Risk Assessment North Coast Java

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1220476-002

Title
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Keywords
Java; Indonesia; Risk index; Exposure; Population density; GDP; Hazard; Storm surge; Sea level rise; Subsidence; Mangroves; Nature-based solutions; Building with Nature.

Summary
Coastal flood risk is increasing globally (Nicholls et al. 2007, Hallegatte et al. 2013). In many South East Asian countries, such as Indonesia, the population is expanding and people are moving to megacities in low-lying coastal zones, thereby largely increasing exposure of people and assets (Yeung 2001, Small and Nicholls 2003). In addition, hazards, such as sea level rise and storminess, can become more extreme as a result of climate change and anthropogenic influences that cause land subsidence and ecosystem deterioration (Yeung 2001, Milly, Wetherald et al. 2002, Nicholls 2004, Knutson, McBride et al. 2010, Hanson, Nicholls et al. 2011). These trends affect vulnerability of coastal communities through endangering food and water security, but also jeopardize future economic development of Asian countries.

More than 140 million people live on the island of Java, Indonesia. A major part of the population resides in the flat and low-lying coastal plain in the North. Tropical rainforests and mangrove forests, once extensively covering Java, disappeared to make place for infrastructure, palm oil, rice fields and aquaculture. Despite not being exposed to intensive natural hazards, such as tsunamis and hurricanes, Northern Javanese coastlines are vulnerable to sea level rise and subsidence (Chaussard, Amelung et al. 2013, van Wesenbeeck, Balke et al. 2015). Ground water extraction for fresh water provisioning is posing a threat to coastline integrity in several cities along the North coast. Consequently, adjacent rural areas start to subside over larger coastal stretches. With little resources for coastal infrastructure this subsidence results in flooding and erosion, challenging the adaptive capacity of coastal communities. This study assesses coastal flood risk for North Java, by considering both exposure and hazards, with the aim to facilitate strategic planning and focus coastal zone management by highlighting areas with high risk levels.

Flood risk is expressed by the consequences of flooding (i.e. exposure and vulnerability) and the likelihood and intensity of flooding (i.e. hazard). Impacts on people and assets exposed to floods can result in casualties and economic loss, depending on the severity of the hazard. In this study, exposure was expressed as a combination of population density and the gross domestic product, whereas the hazard included storm surge, sea level rise and subsidence. To assess the impact of different events, scenarios were composed with different intensities of storm surges and different rates of subsidence for a period of 10 years (Table 1.1 and Table 1.2)The combination of both exposure and hazard highlights hotspots with a relatively large risk (see circled areas in the example in Figure 1.1). To assess possibilities for mitigation of risk in these areas through nature-based solutions, the presence of existing mangroves in the coastal zone was included, based on worldwide data on mangrove presence.

Storm surges with a return period of 1.5, 10 and 100 years were combined with subsidence rates of 0.0, 0.5 and 1.0 m over 10 years. A combination of a storm surge with a return period of 1.5 year and no subsidence resulted already in a flooded area of 1598 km^2 along the entire North coast of Java (Table 1.1). This area is equal to nearly 2.5 times the surface area of the capital region of Jakarta. For this combination of storm surge and subsidence approximately 1.4 million people, which is equivalent to 11% of the population of North Java, lives in these hotspots. Furthermore, a combination of a storm surge with a return period of 100 years and 1.0 meter subsidence over 10 years (Table 1.1) results in an inundated area of 2469 km^2, equal to 3.7 times the area of the capital region. For this scenario we find 2.5 million people living in

the identified hotspots, which is equivalent to 20% of the population of North Java. Results indicate that storm surges with a return period between 1.5 and 100 year have nearly equally large inundated areas, while the inundated area increases with 7% if subsidence of 1.0 m was applied. So even a relatively minor event might result in a large area flooded, and consequently in a large number of inhabitants affected by the flood (inhabitants of the identified hotspots).

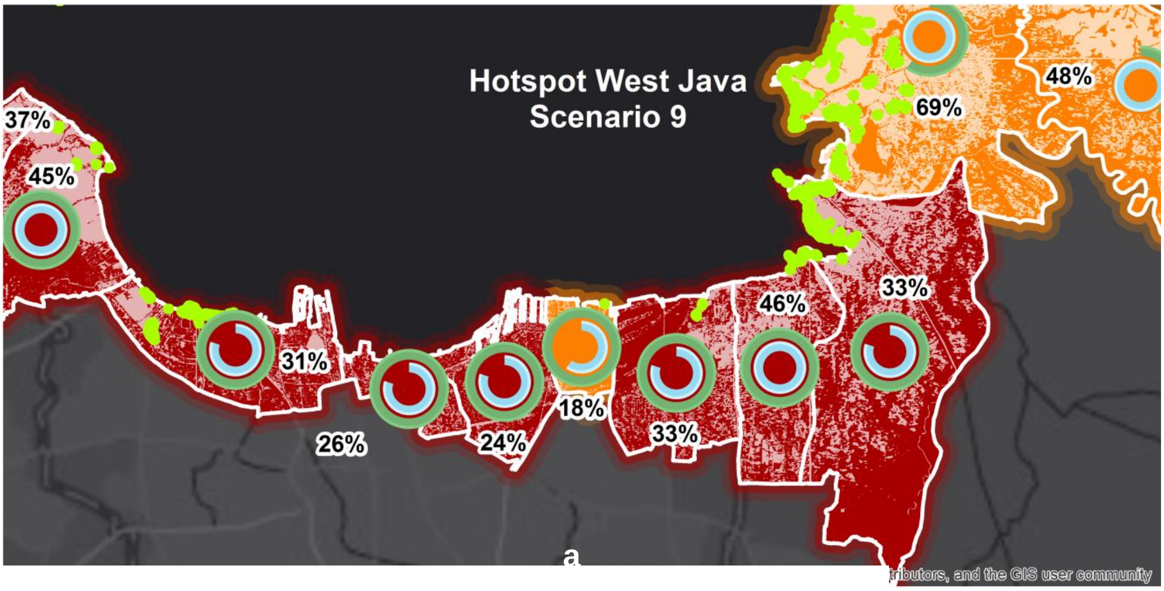
Table 1.1. Inundated area (% of total assessed area and km²) of the (sub-)districts of the north coast of Java per scenario.

		Subsidence		
		0.0 m	**0.5 m**	**1.0 m**
Surge	**1.5 year return period**	14 % 1598 km²	14 % 1598 km²	22 % 2455 km²
	10 year return period	14 % 1609 km²	14 % 1609 km²	22 % 2469 km²
	100 year return period	14 % 1609 km²	14 % 1609 km²	22 % 2469 km²

Table 1.2. Population (% of total assessed population and number of individuals) at hotspots identified within the (sub-)districts of the north coast of Java per scenario.

		Subsidence		
		0.0 m	**0.5 m**	**1.0 m**
Surge	**1.5 year return period**	11% 1,4 10^6	20% 2,5 10^6	20% 2,5 10^6
	10 year return period	12% 1,5 10^6	20% 2,5 10^6	20% 2,5 10^6
	100 year return period	13% 1,6 10^6	20% 2,5 10^6	20% 2,5 10^6

Figure 1.1 Risk map of the north coast of Java. Large numbers (red) indicate large risk. Circles indicate major hotspots presented in more detail in figures 2 and 3.



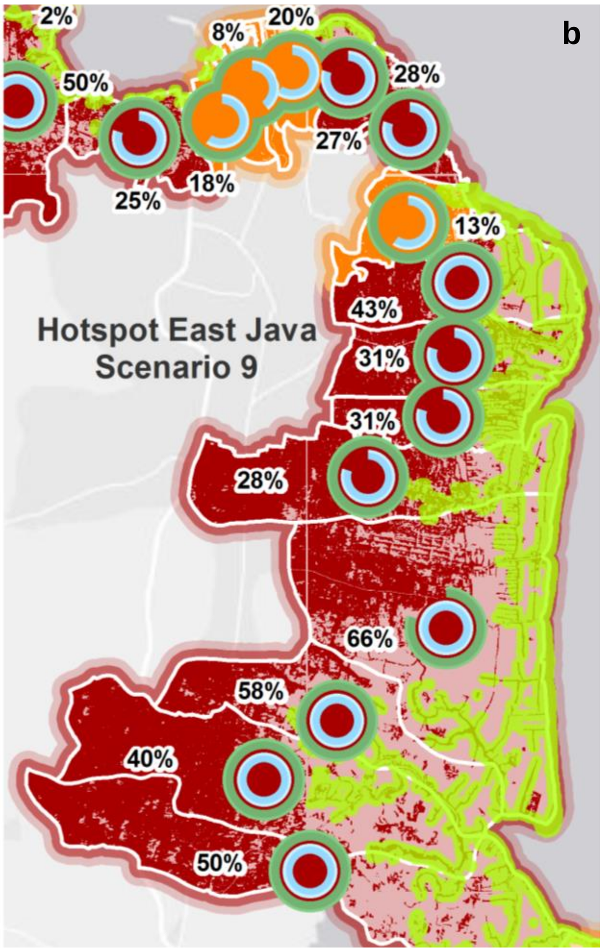


Figure 1.2 Hotspots West Java (a) and East Java (b), indicating sub-districts with a high risk index. The background colour of the sub-districts shows the risk index (orange is 4; red is 5). The inundated part of the area is indicated by white shading and quantified by the percentages. The exposure index is indicated by the green circle segment (full circle equals index 5), while the blue circle segment shows the hazard index (full circle equals index 5).

The risk assessment of the north coast of Java clearly indicates the most vulnerable areas (i.e. hotspots). In general, hotspots were identified at the alluvial plain, where large cities have been developed and are still growing. In these urbanized regions exposure of people and GDP is high (as denoted for the full green circles). For example, 2.5 million people are located in hotspots identified for 1 m subsidence and a storm surge with 100 years return period. Although this area is not subjected to tsunamis and typhoons it is still prone to flooding as it is flat, low-lying and geology allows for subsidence. An important fraction of the total 2469 km^2 flooded for 1 m subsidence and a storm surge with 100 years return period is in these low-lying areas. Moreover, the gentle coastal slope causes large inundated areas of approximately 1600 km2 already by common storm surges with a return period of 1.5 year, with an important fraction of these being again located in hotpots. The inundated area only marginally increases with higher return periods, due to the same gentle

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slope near the coast and the steeper slopes at a larger distance from the coast. Nevertheless, sub-districts can inundate up till 66%, showing the severity of the problem (Figure 1.2).

To mitigate erosion and flood hazard there is a strong tendency to refer to hard infrastructure. However, protecting the 1500 km long coastline of north Java with hard infrastructure is likely not feasible due to lack of financial resources for construction and maintenance on these mostly soft subsoils. Hence, strategic choices that on one hand can adapt to climate change and on the other hand balance environmental, economic, social and cultural objectives need to be made for long-term sustainable coastal management. Recently, Nature-Based solutions (NBS) and Building with Nature gained more interest because of their multi-functionality. A popular example is mangrove restoration for protecting the hinterland. Mangroves attenuate waves, thereby encouraging sediment trapping over the short- and medium term, and potentially increasing elevation over the long-term. Techniques to restore mangroves along eroding coastlines and the associated socio-economic measures have been piloted on large scales for the last 5 years in North Java. Deciding between the most feasible interventions for risk reduction and coastal management can be supported by following Integrated Coastal Zone Management (ICZM) planning processes. To that end, tools for evaluating between strategies and measures, while considering socio-economic, natural and institutional considerations, are used, such as risk assessments.

Current mangrove extent shows that mangroves are also found in the proximity of hotspot locations, especially in the eastern part of Java. A relative high risk (index of 3 and 4) was observed more widespread along the coast, mostly in areas with a large hazard index. Appearance of mangroves was observed in front of many of those more rural areas. This emphasizes the potential of using mangroves as coastal management strategy in these areas. Their conservation in these areas should be top priority to maintain coastal integrity. On the long-run, using Building with Nature measures (for example mangroves, but others as well) in both design and implementation, is likely to be the most cost-effective strategy. Since, in general, hotspots with the largest risk index occur in the more urban areas with less mangrove cover, other hybrid mitigation strategies may apply here. These strategies should be an optimal combination of green and grey measures, integrated into a broader coastal management approach that also includes risk reduction measures like avoidance of high-risk areas, building codes, early warning or evacuation protocols. Finally, including mangroves in a coastal protection strategy, may require more space to accommodate natural ecosystem dynamics.

Version	Date	Author	Initials	Review	Initials	Approval	Initials
0.1	Dec. 2018	Pim Willemsen		Christophe Briere		Frank Hoozemans	
		Amrit Cado van der Lelij					
		Bregje van Wesenbeeck					
0.2	Sept. 2019	Pim Willemsen Amrit Cado van der Lelij Bregje van Wesenbeeck		Miguel de Lucas Pardo		Frank Hoozemans	

Status
final

Contents

1 Introduction

Across the world exposure of people and assets to natural hazards and climate change effects is rapidly rising (Peduzzi, Chatenoux et al. 2012, Woodruff, Irish et al. 2013). In many South East Asian countries, such as Indonesia, population is expanding and people are increasingly moving to megacities that are often situated in low-lying coastal zones or river flood plains (Yeung 2001, Small and Nicholls 2003, Nicholls 2004, Hanson, Nicholls et al. 2011). These areas are amongst the most vulnerable areas in the world (McGranahan, Balk et al. 2007, Nicholls, Herwijer et al. 2007, Woodruff, Irish et al. 2013) as they are directly affected by climate change consequences such as sea level rise and extreme storminess (Milly, Wetherald et al. 2002, Donnelly, Cleary et al. 2004, Knutson, McBride et al. 2010, Lin, Emanuel et al. 2012). Moreover, anthropogenic influences, such as reduced sediment input due to river modifications and coastal infrastructure, encroachment of intertidal areas and floodplains by urban developments (i.e. coastal squeeze) and ground water extraction induced subsidence (Syvitski, Vörösmarty et al. 2005, Syvitski, Kettner et al. 2009, Doody 2013) are increasing the vulnerability of these areas to natural hazards, such as flooding. Moreover, these areas are generally densely populated due to their strategic position and fertile lands (Small and Nicholls 2003, Syvitski and Saito 2007). In Asia these type of coastlines are found in Vietnam, Bangladesh, Thailand and Indonesia, and these are among the most vulnerable coastlines to flooding globally (Nicholls 2004).

The island of Java is mostly formed by volcanic eruptions and now home to more than 140 million people. Most of these people inhabit the flat and low-lying coastal plains in the North of Java. Originally, Java was covered with tropical rainforest and, near rivers and coasts, with mangrove forests. However, most of the forest, especially in the flat coastal zones, has disappeared to make place for major infrastructure, palm oil, rice fields and aquaculture. Despite not being exposed to intensive natural hazards, such as tsunamis and hurricanes, Northern Javanese coastlines are vulnerable to sea level rise and subsidence. Ground water extraction for e.g. fresh water provision might constitute a significant threat to coastline integrity. Ground water extraction is already leading to rapid subsidence of Javanese cities along the North coast (Chaussard, Amelung et al. 2013). As a consequence adjacent rural areas also start to subside and because these often lack resources for protective coastal infrastructure, flooding and erosion occurs regularly and sometimes at large scales (van Wesenbeeck, Balke et al. 2015). The flooding and loss of coastal lands is hampering economic growth and therefore people move to mountainous areas where rapid developments come with new risks, such as an increasing number of landslides.

Current coastal protection and river management interventions focus on river channelization and construction of hard coastal infrastructure. Traditional hard coastal infrastructures for protection of the hinterland are groins, breakwaters, revetments, dams and sea walls. However, protection of the approximately 1500 km north coast of Java, through hard infrastructure is not feasible as construction and maintenance costs and efforts would be enormous, especially considering the soft subsoils (Winterwerp, Borst et al. 2005). Strategic choices need to be made, to sustainably manage the north coast of Java, and balance environmental, economic, social, cultural and recreational objectives. These choices should include not only hard infrastructure options but also nature-based solutions including Building with Nature (BwN). These approaches are gaining ground globally (Cheong, Silliman et al. 2013, Temmerman, Meire et al. 2013). Different terminology has been used for describing nature-based solutions, such as: ecological engineering (Cheong, Silliman et al. 2013), nature-based flood protection

(Van Wesenbeeck, Ijf et al. 2017), ecosystem-based coastal defence (Temmerman, Meire et al. 2013) and building with nature (Ecoshape). An Indonesian example of the latter is mangrove restoration for protecting the hinterland against erosion. Mangroves attenuate waves, thereby encouraging sediment trapping over the short - and medium term (Horstman, Dohmen-Janssen et al. 2015, Willemsen, Horstman et al. 2016), and potential increasing elevation over the long-term (Krauss, McKee et al. 2014). Techniques to restore mangroves along eroding coastlines in North Java have been piloted on large scales for the last 5 years (Whelchel, Reguero et al. 2018).

An Integrated Coastal Zone Management (ICZM) planning process supports making decisions to obtain the most feasible interventions for risk reduction and coastal management. To that end, tools to evaluate between measures while taking into account socio-economic, natural and institutional considerations, can be used to guide strategic choices (Whelchel, Reguero et al. 2018). A risk assessment helps to identify what areas have high risk and can be considered hotspots for action. A system analysis makes a more detailed assessment of the main problem and its' causes and helps to give direction in identification of feasible interventions to mitigate risk. Nature-based solutions can offer some of these interventions. In other cases, for example with higher levels of risk, grey infrastructure interventions may be more appropriate. Both IPCC (Field, Barros et al. 2012) and the Sendai framework for disaster risk reduction (UNISDR 2015) define risk as the product of hazard (probability and intensity), exposure and vulnerability. In this study, a risk assessment is performed looking at hazard and exposure, (van Dongeren, Ciavola et al. 2016, Briere, Burzel et al. 2017). Vulnerability, which is often considered another crucial component of risk, is not included as it is often hard to quantify. The main aim of the current study is to identify areas with a high-risk of flooding and areas where consequences of flooding are large. This may facilitate strategic planning of management strategies and pinpoint areas to prioritize for action.

2 Methods

A risk assessment is used to determine the risk on coastal flooding for the North coast of Java Figure 2.1 Risk is defined as the product of hazard and exposure. Hazard is the probability and intensity of coastal flooding under different scenarios. Exposure is the amount of people and assets exposed to the hazard. Here, exposure is constituted by the number of people and economic activity represented by GDP at the municipal level. Hazard is represented by the flood extent under present and future sea level rise and subsidence. The combination of both hazard and exposure highlights hotspots with a relatively large risk. The method for obtaining risk related indexes was based on methods developed in the FP7 EU project RISC-KIT (see http://www.risckit.eu; van Dongeren, Ciavola et al. (2016)) and used for defining management areas with high-risk of coastal and fluvial flooding, as part of the implementation of the EU Floods Directive in Denmark (Briere, Burzel et al. 2017).

Data for the different parameters were available in different resolutions that all reflected administrative units, such as administrative level 1 (province: "*provinsi*"), level 2 (cities: "*kota*" and regencies: "*kabupaten*"), level 3 (sub-districts: "*kecamatan*") and level 4 (villages: "*desa*"). Data was obtained with the highest resolution possible and aggregated to administrative boundaries of sub-districts, which was used for analysing and presenting the assessment.

Figure 2.1. Map of the North coast of Java, Indonesia.

2.1 Exposure

Exposure is calculated by combining the socio-economic parameters population density and GDP (*PDRB* in Indonesia) (following Whelchel, Reguero et al. 2018). Both are selected because they are comprehensive parameters, presenting the socio-economic status of a certain area. Also, both parameters are available for the entire coastal zone of Java.

Population statistics are obtained via the Central Bureau of Statistics (BPS) and the Geospatial Information Agency (BIG). The data set provides information on population count in 2010 at the lowest administrative level (i.e. village; level 4). The GDP (Deltares, DHV et al. 2012), measured in 2010, is obtained from the BPS, providing data per regency (level 2) and is translated to data per sub-district (level 3). This translation to a higher resolution, without increasing the level of detail of the data, is executed to keep information from parameters available with higher resolution. The population density is obtained by aggregating the data per village (level 4) to sub-districts. First the population density data is rasterized, followed by taking the average of all raster cells within a sub-district.

Both the population density data and the GDP data are converted to a standardized index for giving equal weight to both parameters in the exposure index. Ranking of population and GDP is based on the ranking for the hazard index in van Dongeren, Ciavola et al. (2016). Six classes from 0 to 5 are used (none, very low, low, medium, high and very high). Since population or GDP was defined for all sub-districts, class 0 (none) is ignored. The sub-districts are equally distributed over the five classes (i.e. equal number of sub-districts per class), again to have an equal weight when combining both parameters in the exposure index. The distribution results in 5 classes with the largest values for population density as well as GDP in the highest class (Table 2.1 and Table 2.2).

Table 2.1 distribution of population density (people/hectare) with the boundaries of the five classes.

Class	Minimum value (<)	Maximum value (>=)
1 – very low	-	6.92
2 – low	6.92	10.63
3 – medium	10.63	15.45
4 – high	15.45	29.74
5 – very high	29.74	-

Table 2.2 distribution of GDP (Rupiah per capita per year with the boundaries of the five classes.

Class	Minimum value $*10^6$ (<)	Maximum value $*10^6$ (>=)
1 – very low	-	3.17
2 – low	3.17	6.04
3 – medium	6.04	11.05
4 – high	11.05	19.23
5 – very high	19.23	-

The exposure index is calculated by equally combining the distribution for population density and GDP (equation 2.1.1). The range of the exposure index is equal to the range of the classes from the input parameters population density and GDP, and results in five indices (1-5) with the largest index corresponding to the largest exposure. The resulting values are rounded up to the nearest integer.

$$Exposure\ index = \sqrt{Population\ density * GDP}$$ *Equation 2.1.1*

2.2 Hazard

The hazard parameter is considered here as the potential flood extent, which is taken as the area below local mean sea level. Parameters influencing the flood extent at the north coast of Java, currently and in the (near) future, are sea level rise, extreme storm conditions (Sofian 2010, Muis, Güneralp et al. 2015, Muis, Verlaan et al. 2016, Suroso and Firman 2018) and anthropogenic influences, such as subsidence (Erkens, Bucx et al. 2015, Sarah and Soebowo 2018). The hazard in this assessment is limited to relative sea level rise. Extreme conditions, such as tsunamis and hurricanes, were not taken into account.

The flood extent is based on a Digital Surface Model (DSM) collected by the Terra Synthetic Aperture Radar (TerraSAR), with a resolution of 5 meters for Java in 2014 (Suroso and Firman 2018). The DSM is not corrected for buildings and canopy. Meteorological and climatological impacts are included by considering storm surge and sea level rise. The DSM is stored as integers, not allowing decimals.

Large storm surges occur when extreme wind events (e.g. statistically occurring once every year or decade) locally increase the water level. Storm surges with a return period of 1.5, 10 and 100 year were obtained from a global hydrodynamic model, by calculating the surge with a spatial resolution of 1/2° (~50km) in the deeper parts of the ocean towards 1/20° (~5 km) in shallow coastal areas (Muis, Verlaan et al. 2016). Surge levels are transposed to coastal segments taken from DIVA (Hinkel and Klein 2009). The average sea level rise in the Java sea is estimated to be 0.006 m/year, by comparing the average sea level between 1993 and 2000 with the average sea level between 2001 and 2008 (Sofian 2010). Anthropogenic influences are considered by including subsidence. Subsidence was estimated to vary between 0.01 to 0.1 m/year which are considered a low and high scenario for subsidence prone areas based on literature (Chaussard, Amelung et al. 2013, Sarah and Soebowo 2018). Based on a geological map (Geological Research and Development Centre 1999) each area is classified as being prone to subsidence or not. Geological classes that were identified as being prone to subsidence are described in Appendix 1: selecting geological classes prone to subsidence.

For the hazard index, different scenarios are run that are composed of different parameter values. The scenarios aim to reflect potential future trends resulting in relative sea level rise over a period of 10 years. Sea level rise, subsidence and storm surge parameters are combined to calculate possible flood extent in 10 years. Sea level rise remains constant with a value of 0.006 m/year (Sofian 2010), equal to 0.06 m over 10 year. Values for subsidence are set at 0.0m, 0.5 m and 1.0 m over a period of 10 years, which is a conservative estimate (Sarah and Soebowo 2018). In Jakarta and Semarang subsidence rates vary spatially between 1 and 10 cm/year generally. Rates in Jakarta can reach up to 25-28 cm/year. Subsidence rates in Pekalongan were observed to be 4.8-10.8 cm/year, while being 1.0-2.7 cm/year in industrial and built areas in Surabaya (Sarah and Soebowo 2018). Additionally, three different return periods (1.5, 10 and 100 years) for storm surge are used, where a return period of 1.5 years represents a common occurring event and a return period of 100 year a rare event. A total of nine scenarios are obtained through combining both parameters (Table 2.3).

Table 2.3 Scenarios developed by combining storm surge and subsidence.

		Subsidence		
		0.0 m	**0.5 m**	**1.0 m**
Surge	**1.5 year return period**	Scenario 1	Scenario 2	Scenario 3
	10 year return period	Scenario 4	Scenario 5	Scenario 6
	100 year return period	Scenario 7	Scenario 8	Scenario 9

The DSM is referred to mean sea level (Figure 2.2; top panel). All other data are converted to raster data with the raster characteristics of the DSM to be able to execute raster calculations. Storm surge data is captured in point data and converted to raster data using nearest neighbour interpolation. This is done in ArcMAP by creating Thiessen polygons (i.e. any location within a Thiessen polygon is closest to the point associated with) and converting the resulting polygons to raster data. The geological data for determining areas where subsidence can occur were available in polygons and converted to raster data (Figure 2.2; bottom panel). The data was combined into a revised DSM, addressed as DSM':

$$DSM'(relative\ to\ mean\ water) = DSM - SLR\ - subsidence - surge \qquad \textit{Equation 2.2.1}$$

Wherein:

$SLR = 0.06m$

$subsidence = 0.0m, 0.5m\ or\ 1.0m\ (if\ applicable)$

$$surge = in\ meter\ with\ a\ 1.5, 10\ or\ 100\ year\ return\ period$$

After obtaining the DSM', the inundated and dry raster cells per sub-district are extracted and then the relative and absolute inundated area per sub-district are calculated. These values are distributed over multiple classes, similar to the parameters in the exposure index. Six classes from 0 to 5 are used (none, very low, low, medium, high and very high), following van Dongeren, Ciavola et al. (2016). The raster cells of one single sub-district (Wonoasih; Kota Probolinggo) are not inundated. To consistently use 5 classes, index 0 (none) is ignored. A quantile distribution is obtained for all scenarios using the values for DSM' (Table 2.4). To get a better distinction of the hotspots, six quantiles are defined for the hazard index with the smallest two included in index 1.

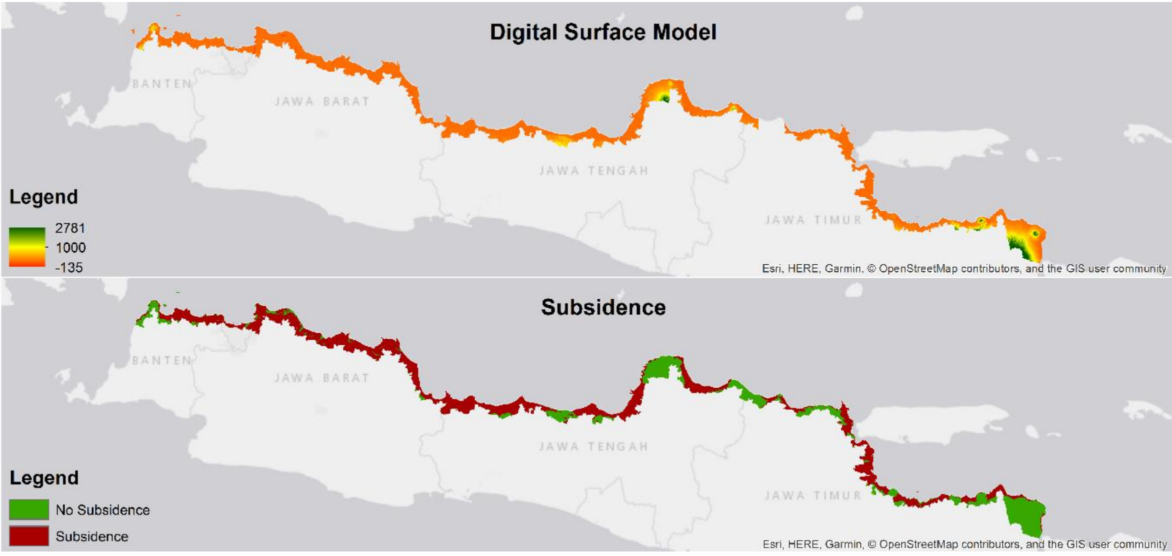

Figure 2.2 DSM (top panel) of the north coast of Java with high and relative safe areas in red/orange and low relative unsafe areas in yellow/green; and areas were subsidence occurs, derived from geological maps (bottom panel).

Table 2.4 distribution of the hazard index with the boundaries of the five indices.

Index	Minimum value (<)	Maximum value (>=)
1 – very low	-	$3.6262 * 10^{-2}$
2 – low	$3.6262 * 10^{-2}$	$1.0434 * 10^{-1}$
3 – medium	$1.0434 * 10^{-1}$	$1.9969 * 10^{-1}$
4 – high	$1.9969 * 10^{-1}$	$3.4956 * 10^{-1}$
5 – very high	$3.4956 * 10^{-1}$	$6.9369 * 10^{-1}$

2.3 Risk

The risk index is obtained by combining the hazard index and exposure index (van Dongeren, Ciavola et al. 2016, Whelchel, Reguero et al. 2018). The risk takes both the hazard and exposure index into account with an equal weight (Equation 2.2.1). The resulting risk index has the same distribution as the hazard and exposure index. The resulting values are rounded up to the nearest integer (1-5). The risk index is used to highlight hotspots (sub-districts with a high risk index). Since the risk index is derived from the hazard and exposure, the contribution of respectively hazard and exposure to the risk can be identified.

$$Risk\ index = \sqrt{Hazard\ index * Exposure\ index} \qquad \text{Equation 2.2.1}$$

2.4 Building with Nature

Wetlands attenuate waves and mitigate storm surges (Resio and J. Westerink 2008, Gedan, Kirwan et al. 2011). Given the presence of mangroves in the Indo-Pacific region (Lovelock, Cahoon et al. 2015), the opportunity of using them to mitigate coastal flood and erosion risks is high. Nevertheless, to sustainably use mangroves as a coastal protection strategy, sufficient sediment should be available to keep up with SLR and subsidence (Lovelock, Cahoon et al. 2015). To assess the potential of existing mangroves to reduce present risk in the current study, the occurrence of mangroves in the coastal zone is mapped. Worldwide mangrove data collected by Giri, Ochieng et al. (2011), is used to indicate potential of mangroves to reduce flood risk in hotspot areas.

3 Results

3.1 Exposure index

Population density (Figure 3.1; top panel) is high in the larger cities, such as Jakarta, Semarang and Surabaya, and to a lesser extent, Cirebon, Tegal, Kramat, Pekalongan, Jepara, Tuban and Probolinggo (Figure 2.1). GDP (Figure 3.1; middle panel) is especially high in the surrounding areas of the three large cities (Jakarta, Semarang and Surabaya). Therefore, exposure index, which is constituted by the combination of population and GDP highlight the areas near some of the large cities, since both population density and GDP are large (Figure 3.1 bottom panel). A complete overview of the exposure index of all scenarios can be found in Appendix 2 and Appendix 3.

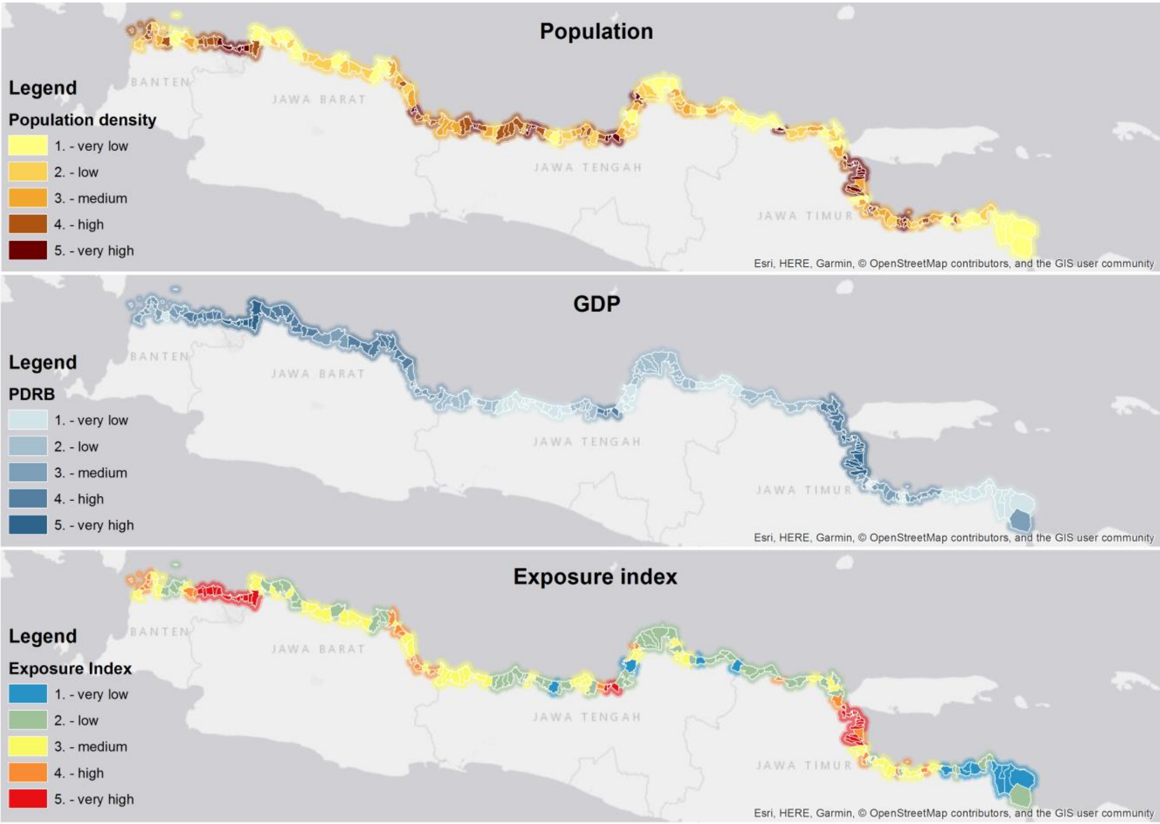

Figure 3.1 Exposure (bottom panel) of the north coast of Java, expressed using population density (top panel) and GDP (middle panel). Large numbers indicate a large population, GDP and/or exposure.

3.2 Hazard index

In general, large values for the hazard index are observed eastward from Jakarta, eastward from the Eretan Bay, northward from Babakan and Tegal, in areas near Semarang and northward and southward from Soerabaja. Differences between a common (1. common surge occurring once every 1.5 years and no subsidence) and extreme (9. extreme surge occurring once every 100 years with 1.0m subsidence) scenarios were clearly observed (Figure 3.2 and Figure 3.3). Differences are reflected in the number of sub-districts with high values for the hazard index, with a large amount of unsafe sub-districts in the extreme scenario 9. Comparing total areas that are inundated between scenarios shows that the total inundated area due to a common storm surge with a return period of 1.5 year (and 0.0m subsidence; scenario 1) amounts to 14% of the total area of the sub-districts at the north coast of Java (Table 3.1). The increase of the total inundated area when applying a scenario with 100 year storm surge (and 0.0m subsidence; scenario 7) is negligible. However, the total inundated area due to a storm surge with a return period of 100 year and 1.0m subsidence (scenario 9) is 22%. The inundated area due to common flooding (scenarios 1, 2 and 3) is already relatively large and the increase in this area with more extreme scenarios is relatively little. A complete overview of the hazard index of all scenarios can be found in Appendix 2 and Appendix 3.

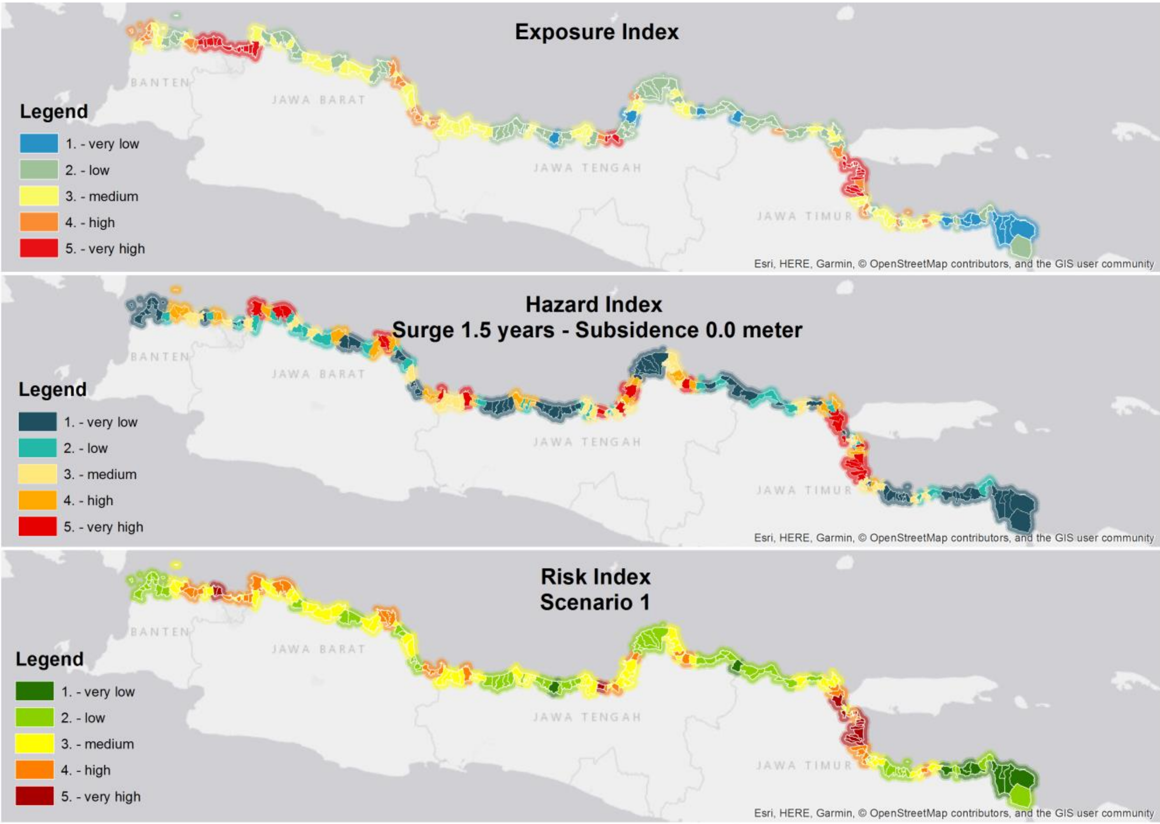

Figure 3.2 Risk of the north coast of java. The top plot shows the exposure index, the centre panel shows the hazard index for scenario 1 (SLR 0.06m, subsidence of 0.0m, surge with a return period of 1.5 year). The risk index (bottom panel) combines both the exposure and hazard index. Large numbers (red) indicate a large exposure, hazard and/or risk.

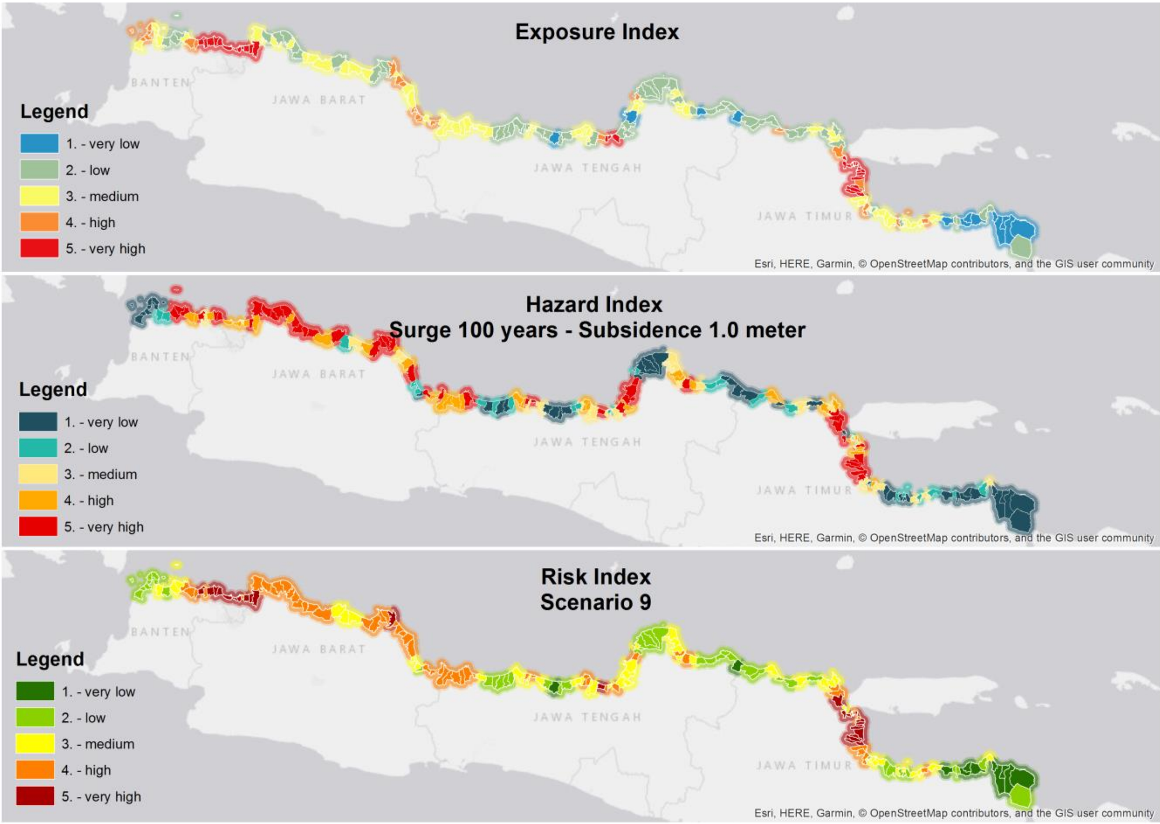

Figure 3.3 Risk of the north coast of java. The top plot shows the exposure index, the centre panel shows the hazard index for scenario 7 (SLR 0.06m, subsidence of 1.0m, surge with a return period of 100 year). The risk index (bottom panel) combines both the exposure and hazard index. Large numbers (red) indicate a large exposure, hazard and/or risk.

Table 3.1 Inundated area (% of total assessed area and km^2) of the (sub-)districts of the north coast of Java per scenario. The scenarios highlighted by a bold and italic font (extreme scenario) are specifically mentioned in this section

		Subsidence		
		0.0 m	**0.5 m**	**1.0 m**
Surge	**1.5 year return period**	***14 %*** ***1598 km^2***	14 % 1598 km^2	22 % 2455 km^2
	10 year return period	14 % 1609 km^2	14 % 1609 km^2	22 % 2469 km^2
	100 year return period	14 % 1609 km^2	14 % 1609 km^2	***22 %*** ***24.69 km^2***

3.3 Risk index

High risk indices (index of 5) are found at the sub-districts where both exposure and hazard are large. For the mild scenario 1 (Fig. Figure 3.3), this occurs in sub-districts near Jakarta, near Semarang and near Soerabaja. For the extreme scenario 9 (Figure 3.4), high risk indices appear in an increasing number of sub-districts near Jakarta, a sub-district northward from Cirebon and an increasing number of sub-districts near Soerabaja. Sub-districts with a relatively large risk index (index of 3-4) occurred more often. In general, surrounding the areas with a risk index of 5 and occurring in the more rural areas over the entire stretch of assessed coastline. A complete overview of the risk index of all scenarios can be found in Appendix 2 and Appendix 3.

3.4 Hotspots with a high and relative high risk index

Hotspot areas, where risk is highest in scenario 9 (storm surge with a 100 year return period, subsidence of 1.0m and SLR of 0.06m), are identified at west (Figure 3.4), central (Figure 3.5) and east Java (Figure 3.6), i.e. near Jakarta, Semarang and Soerabaja, respectively (Figure 2.1). In these areas, the exposure index is 5 (green circle segments at the middle, scenario 1, and bottom, scenario 9, panels), but the hazard index (blue circle segments at the middle, scenario 1, and bottom, scenario 9, panels), is not always equal to 5. Only at the hotspot in central Java the contribution of hazard to the risk index is larger than the contribution of exposure. Although the highest risk has been observed near the large coastal cities, due to both a large exposure and hazard, areas with only a large hazard index are widespread along the coast (Fig. Figure 3.4). Moreover, a relative high risk index (3-4), is observed more widespread along the entire stretch of the coast. Both surrounding the hotspots with a risk index of 5 and in the more rural areas the hazard is high, although the exposure as used in the present assessment is slightly less. Finally, Table 3.2 shows the population (% of total assessed population and number of individuals) at hotspots identified within the (sub-)districts of the north coast of Java per scenario.

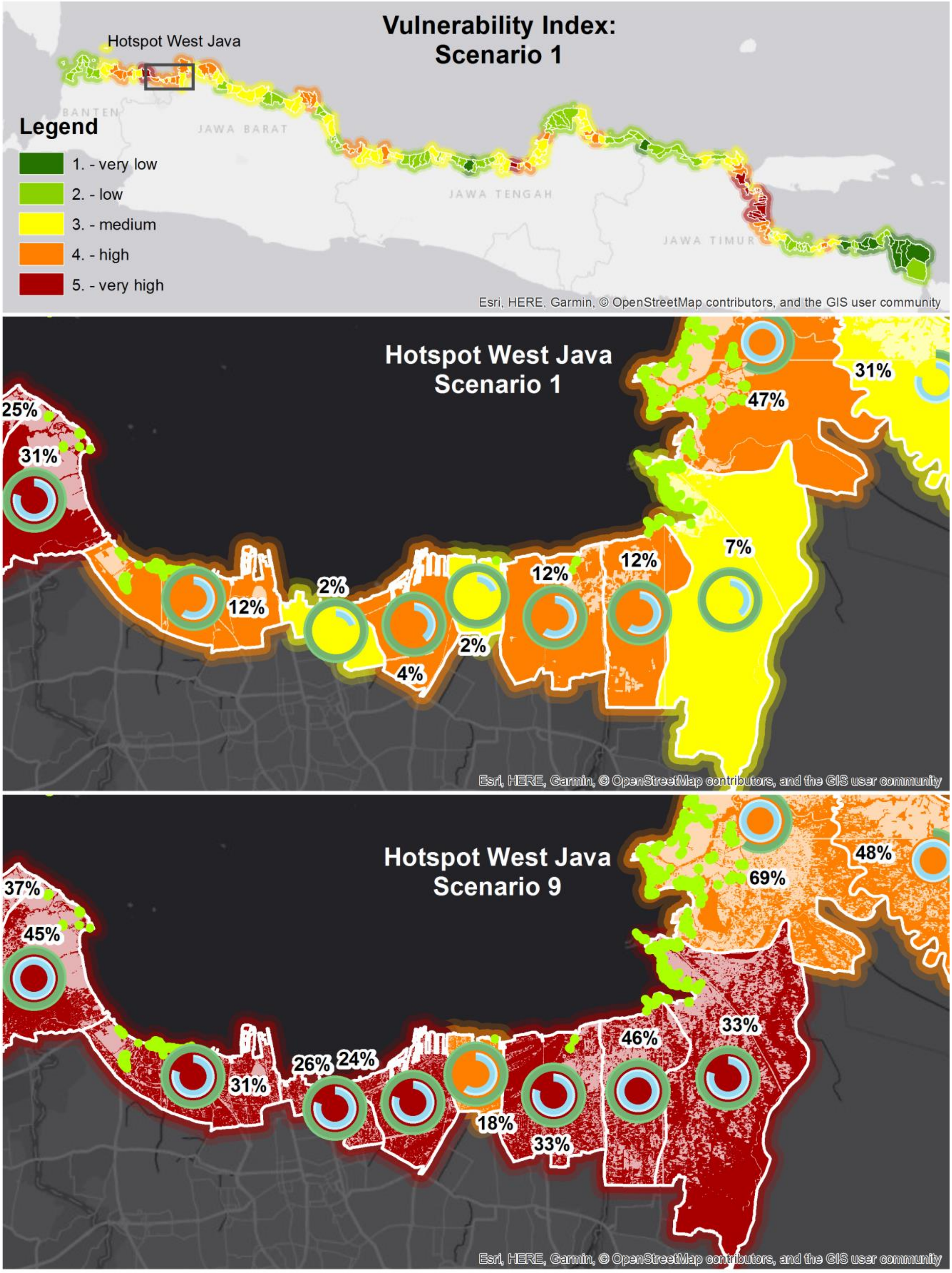

Figure 3.4 Hotspots West Java, indicating sub-districts with a high risk index. The top panel shows the risk index (scenario 1; SLR of 0.06m, subsidence of 0.0m, surge with a return period of 1.5 year) for all sub-districts at the North coast of Java. The black box indicates the area with the largest risk index in the western part of Java and shows the extent of the centre and bottom panel. The background colours of the sub-districts in the centre panel show the risk index. The inundated part of the area is indicated by a white shading, and

quantified by the percentages. The exposure index is indicated by the green circle segment (full circle equals index 5), while the blue circle segment shows the hazard index (full circle equals index 5). The bottom panel contains the same information as the centre panel, however for scenario 9 (SLR of 0.06m, subsidence of 1.0m, surge with a return period of 100 year). Mangrove occurrence (Giri, Ochieng et al. 2011) is indicated with light green shading in the bottom panels.

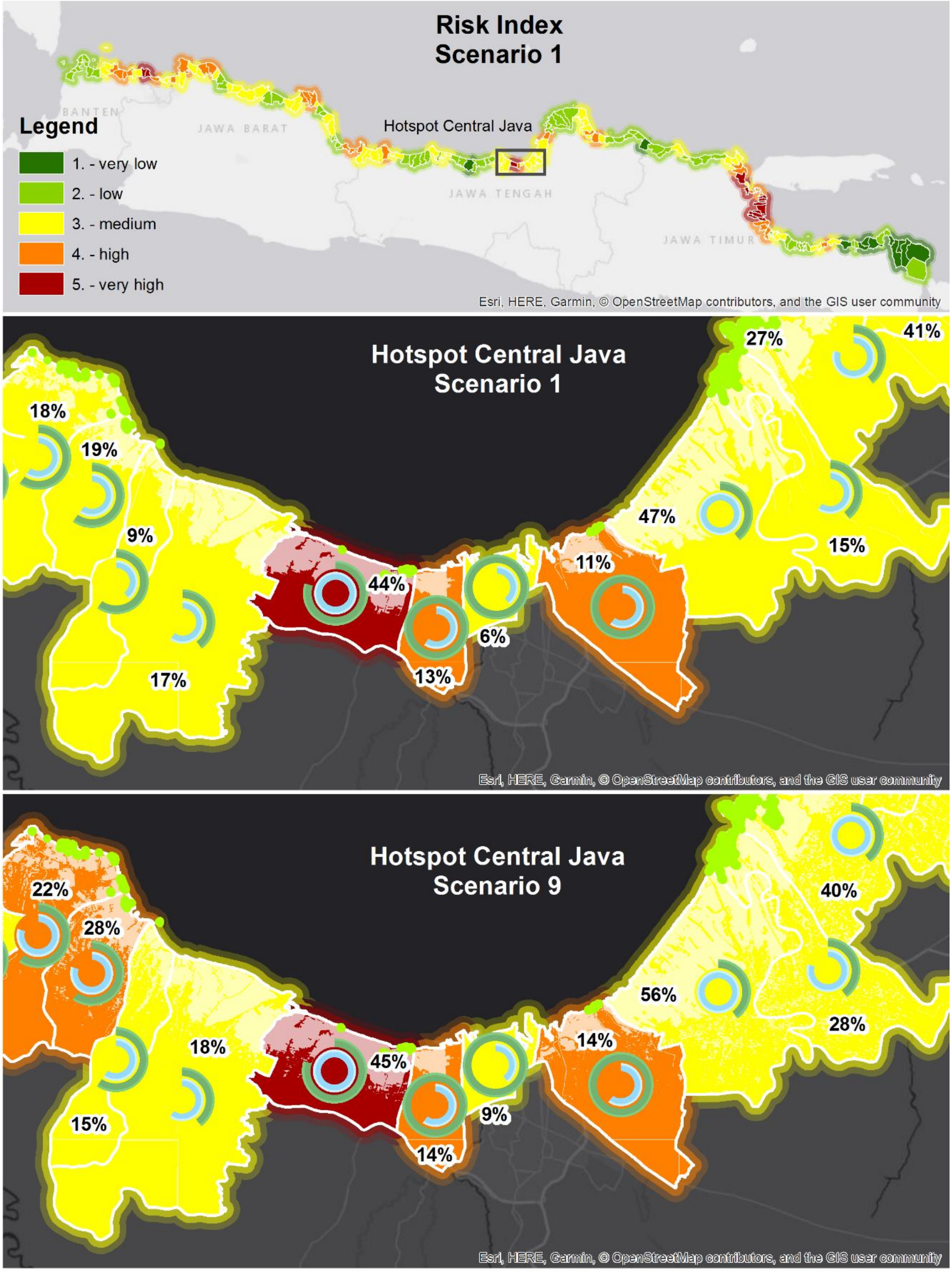

Figure 3.5 Hotspots Central Java, indicating sub-districts with a high risk index. The top panel shows the risk index (scenario 1; SLR of 0.06m, subsidence of 0.0m, surge with a return period of 1.5 year) for all sub-districts at the North coast of Java. The black box indicates the area with the largest risk index in the central part of Java and shows the extent of the centre and bottom panel. The background colours of the sub-districts in

the centre panel show the risk index. The inundated part of the area is indicated by a white shading, and quantified by the percentages. The exposure index is indicated by the green circle segment (full circle equals index 5), while the blue circle segment shows the hazard index (full circle equals index 5). The bottom panel contains the same information as the centre panel, however for scenario 9 (SLR of 0.06m, subsidence of 1.0m, surge with a return period of 100 year). Mangrove occurrence (Giri, Ochieng et al. 2011) is indicated with light green shading in the bottom panels.

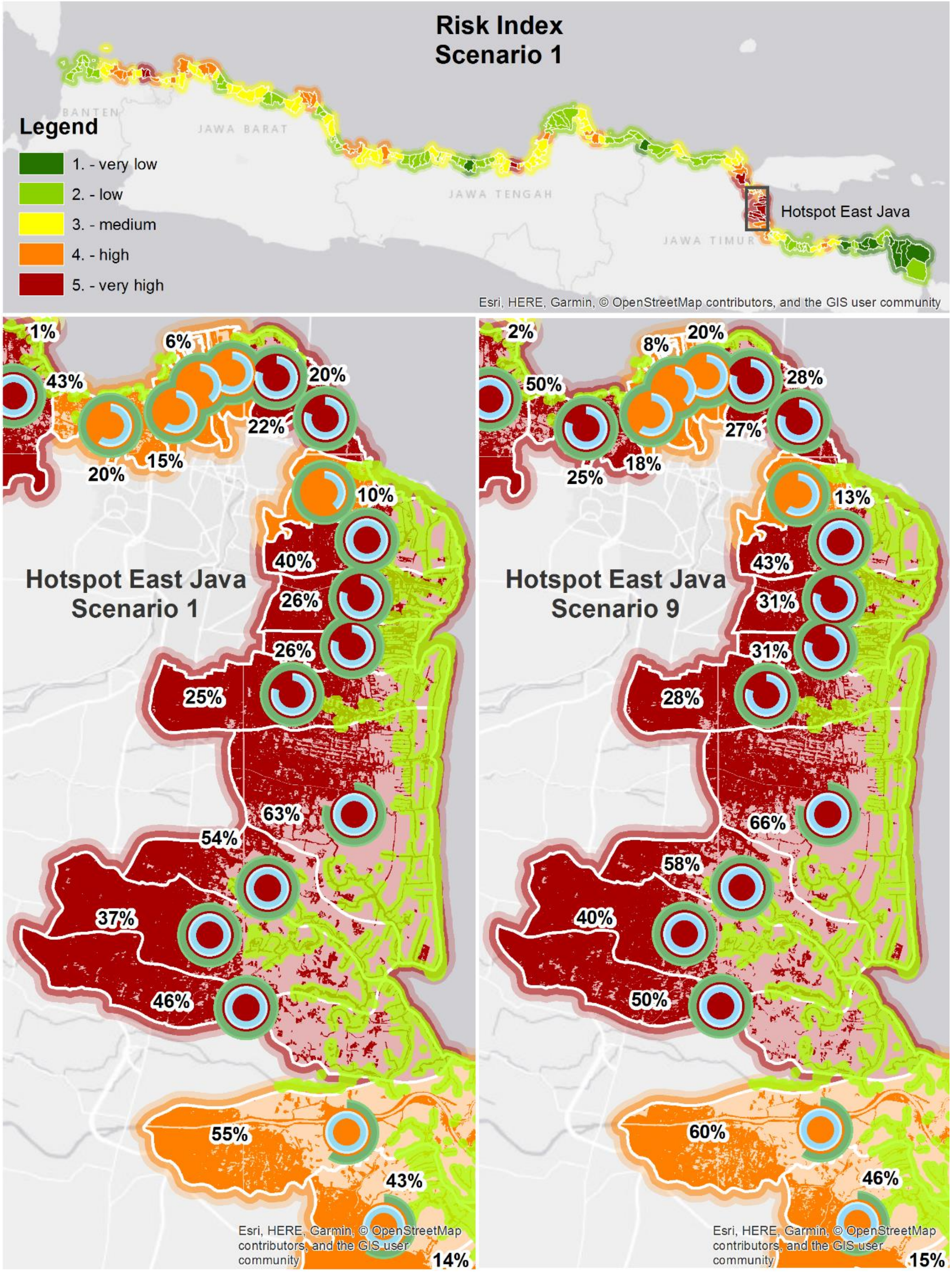

Figure 3.6 Hotspots East Java, indicating sub-districts with a high risk index. The top panel shows the risk index (scenario 1; SLR of 0.06m, subsidence of 0.0m, surge with a return period of 1.5 year) for all sub-districts at the North coast of Java. The black box indicates the area with the largest risk index in the eastern part of Java and shows the extent of the centre and bottom panel. The background colours of the sub-districts in the centre panel show the risk index. The inundated part of the area is indicated by a white shading and

quantified by the percentages. The exposure index is indicated by the green circle segment (full circle equals index 5), while the blue circle segment shows the hazard index (full circle equals index 5). The bottom panel contains the same information as the centre panel, however for scenario 9 (SLR of 0.06m, subsidence of 1.0m, surge with a return period of 100 year). Mangrove occurrence (Giri, Ochieng et al. 2011) is indicated with light green shading in the bottom panels.

Table 3.2. Population (% of total assessed population and number of individuals) at hotspots identified within the (sub-)districts of the north coast of Java per scenario.

		Subsidence		
		0.0 m	**0.5 m**	**1.0 m**
Surge	**1.5 year return period**	11% 1,4 10^6	20% 2,5 10^6	20% 2,5 10^6
	10 year return period	12% 1,5 10^6	20% 2,5 10^6	20% 2,5 10^6
	100 year return period	13% 1,6 10^6	20% 2,5 10^6	20% 2,5 10^6

3.5 Mangrove occurrence

Mangroves are observed along the entire coastline of the north coast of Java (Figure 3.7). The concentration of mangroves is most abundant adjacent to the Ciasem and Eretan Bay, northward from Semarang and in the coastal areas surrounding Soerabaja. Mangroves are observed in the sub-districts with a high risk index (hotspots). However, presence of mangroves is only little near the hotspots in west and central Java (Figure 3.4 and Fig. Figure 3.5, respectively). Still mangroves are present, indicating the suitability for growth near the hotspots. The hotspots with the highest risk index in east Java (Figure 3.6), southward from Soerabaja show abundant mangroves at the coastal zone and fluvial areas, which potentially contribute to coastal protection already. In general, mangrove occurrence near hotspots with a relative high risk index (3 / 4) as a consequence of a large hazard index, is observed to be larger.

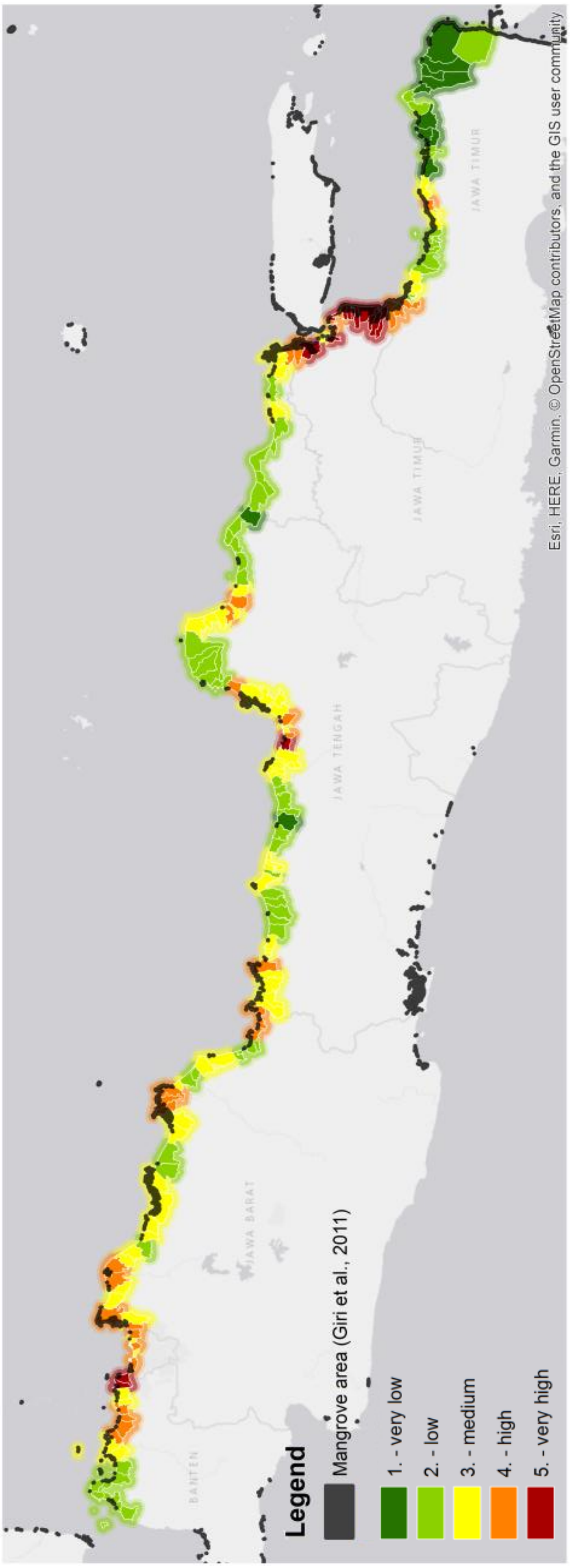

Figure 3.7 Mangrove occurrence at the coastal area of Java (black shading), visualised on top of the sub-districts showing the risk index for scenario 1.

4 Discussion, conclusions and recommendations

North Java coastal zones are largely low lying and consist of soft clayey sediments. This makes them extremely vulnerable to a combination of sea level rise and subsidence caused by deep groundwater extraction. In the current assessment the coastal flood risk is assessed for North Java with the aim to inform on the location of areas with a high-risk of flooding and to facilitate strategic planning and decision-making on priority areas for coastal management and possible interventions. The risk assessment was conducted to make a first estimate of the amount of land prone to flooding, the GDP at risk and the number of people that will be impacted. This assessment highlights hotspot areas where flood hazard and the amount of people and assets affected are large. This is a first step in planning intervention strategies and future developments along Javanese coastlines.

Results indicate that extensive areas are already inundated by common storm surges with a return period of 1.5 year, due to the gentle coastal slope. Moreover, inundated area only shows a marginal increase with increasing return periods, due to the same gentle slope near the coast and the steeper slope distant from the coast. Nevertheless, in this low-lying flood-prone coastal zone population density is high, emphasizing the urgency of action and feasible intervention strategies.

Hazard analyses in this study shows that with the most benign scenario, which consists of a storm surge of 1.5 year and no additional subsidence, already a large part of the north coast is inundated. For storms with return periods up to 100 years, increases in flood extent are marginal (14.07% and 14.17% inundated area, for storm surges with a return period of 1.5 and 100 years, respectively). However, including subsidence of 1.0 m raises the inundated area to 22%, which is an increase of approximately 50%. This increase is not observed when increasing the amount of subsidence from 0.0m to 0.5m. This is probably due to the format of the Digital Surface Model (DSM), which is stored in integers and as a consequence only incremental differences of a full value show visible results.

The risk assessment clearly indicates that most vulnerable areas are in line with the used socio-economic parameters. For example, hotspots appear in the alluvial plain, where large cities have developed and are still growing. In these urbanized regions exposure of people and GDP is high. The area is naturally provided with fertile soils, abundant fresh water and access to the coast. However, due to the geology, flat coastal slopes and sensitivity to subsidence this area is prone to coastal flooding. Naturally, coastal management interventions are mainly focussed on areas with most people and economic turn-over as only in these areas the large expenditure that comes with protective infrastructure might pay off (Hallegatte, Green et al. 2013). However, non-structural interventions such as managed re-alignment can be effective in rural areas as well. Those more cost-effective interventions imply giving up parts of the coastal zone, which might be better achieved in rural than urban areas. Moreover, the population and environment can benefit from management and preservation of natural systems. These systems will aid in mitigating flood effects and provide essential recreation space for the growing urban population.

Current mangrove extent is presented in this study as mangroves can constitute an element of a coastal management strategy for both rural and urban areas. Where mangroves are still present, their conservation should be top priority to maintain coastal integrity. Besides the ability of mangroves to dampen waves and to mitigate erosion, mangroves deliver other services. For instance, they are of vital importance for nearshore and offshore fisheries. Additionally, they improve water quality and offer cultural goods, as people process leaves and seeds to make paint, lemonade and krupuk. Mangroves are also found in the proximity of hotspot locations, especially in the eastern part of Java. A relative high risk (index of 3 and 4) was observed more widespread along the coast, due to high values for the hazard component of the index. Appearance of mangroves was observed in front of many of those more rural areas. This emphasizes the potential use of mangroves as coastal management strategy in these areas. In the long-run, using Building with Nature type of measurements like mangrove as protection strategy, can be more cost-effective (Temmerman, Meire et al. 2013, Whelchel, Reguero et al. 2018). Moreover, when using mangroves as coastal protection strategy, space should be available in the nearshore area to accommodate the dynamics of the natural ecosystem. If this accommodation space can be found in rural areas, a potential sustainable coastal protection strategy can be applied.

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A Selectin geological classes prone to subsidence

Geological classes prone to subsidence:

- Swamp deposits
- Alluvium
- Coastal deposits
- Deltaic deposits
- Alluvium and Coastal Deposits
- Alluvial Fan
- Alluvial and Lake Deposits
- Older Alluvium
- Flood Plain Deposits

Other geological classes:

- Argohalangan Morphocet
- Basalt of Pinang Volcano
- Beach Ridge Deposit
- Coralline Limestone
- Bagor Formation
- Baluran Volcanic Rocks
- Young Ijen volcanic rocks
- Jembangan Volcanics
- Jembangan Volcanics
- Reef Limestone
- Shallow marine deposite
- Lower Quartenary Volcanics
- Basalt Porphyr
- Old volcanic rocks of danau
- Volcanic rock of Gede
- Jombang Formation
- Kabuh Formation
- Kaligetas Formation
- Reef Limestone
- Terrace deposits
- Trachite
- Upper Banten Tuff
- Volcanics Product Of Gede
- Old Ijen volcanic rock
- Volcanic Rock of Marikangen
- Damar Formation
- Lidah Formation
- Pucangan Formation
- Terrace Deposits
- Cemara Tiga Debris
- Old volcanic product - breccia
- Rante, Merapi volcanic rock
- Volcanic brecccia
- Young volcanic rocks of danau
- Genuk Volcanic rocks

- Muria Lava
- Pandak Volcanic rock
- Older Volcanic RocksTuff
- Upper Banten Tuff
- Muria Tuff
- Rabano tuff
- Young eruption product of Ciremai
- Young Volcanic product
- Bulu Formation
- Kerek Formation
- Lengkong Formation
- Parigi Formation
- Halang Formation
- Lebakwangi Member
- Menuran Formation
- Tuff Member
- Limestone member
- Ngrayong Formation
- Wonocolo Formation
- Limestone member
- Metamorphic Rock
- Prupuh Limestone member
- Kunjung Formation Upper Member
- Kalibiuk Formation
- Sandstone Member
- Kaliwangu Formation
- Leprak Formation
- Cimanceuri Formation
- Paciran Formation

Tapak Formation

B Exposure, hazard and risk index for all scenarios

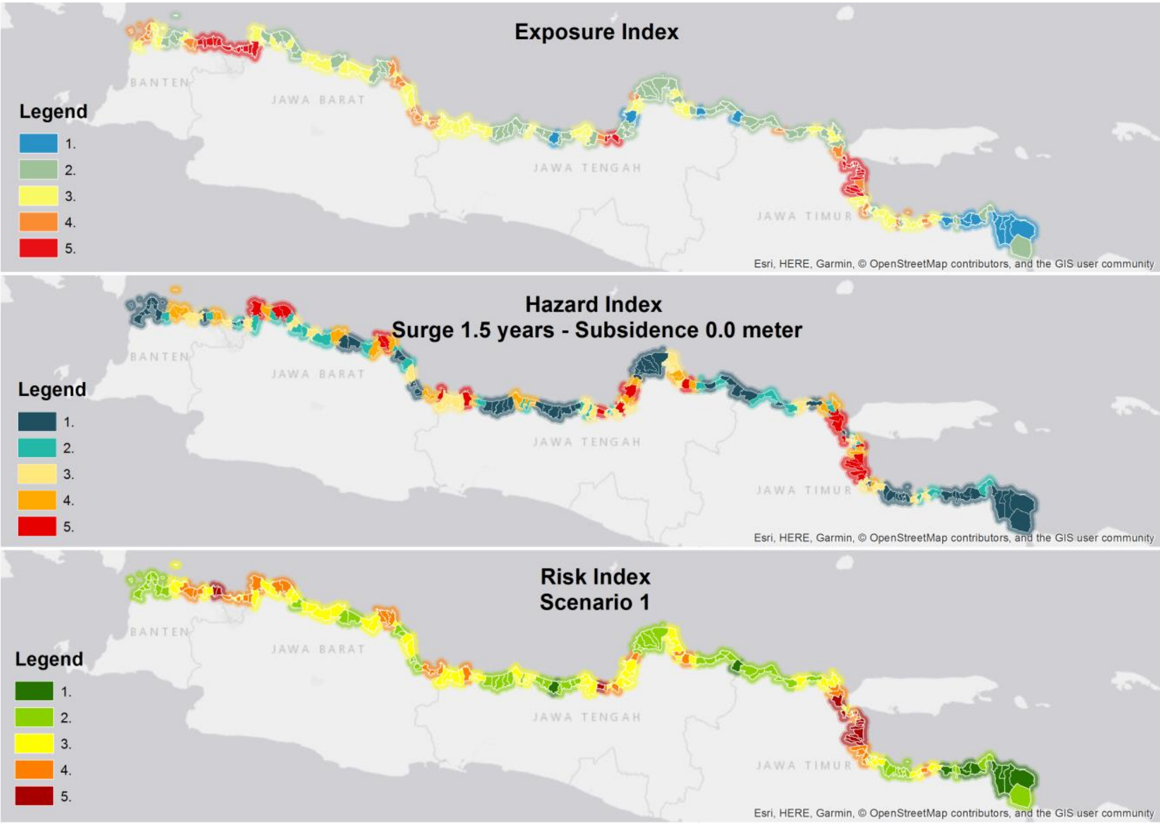

Figure B.1 Risk of the north coast of java. The top plot shows the exposure index, the centre panel shows the hazard index for scenario 1 (SLR 0.06m, subsidence of 0.0m, surge with a return period of 1.5 year). The risk index (bottom panel) combines both the exposure and hazard index

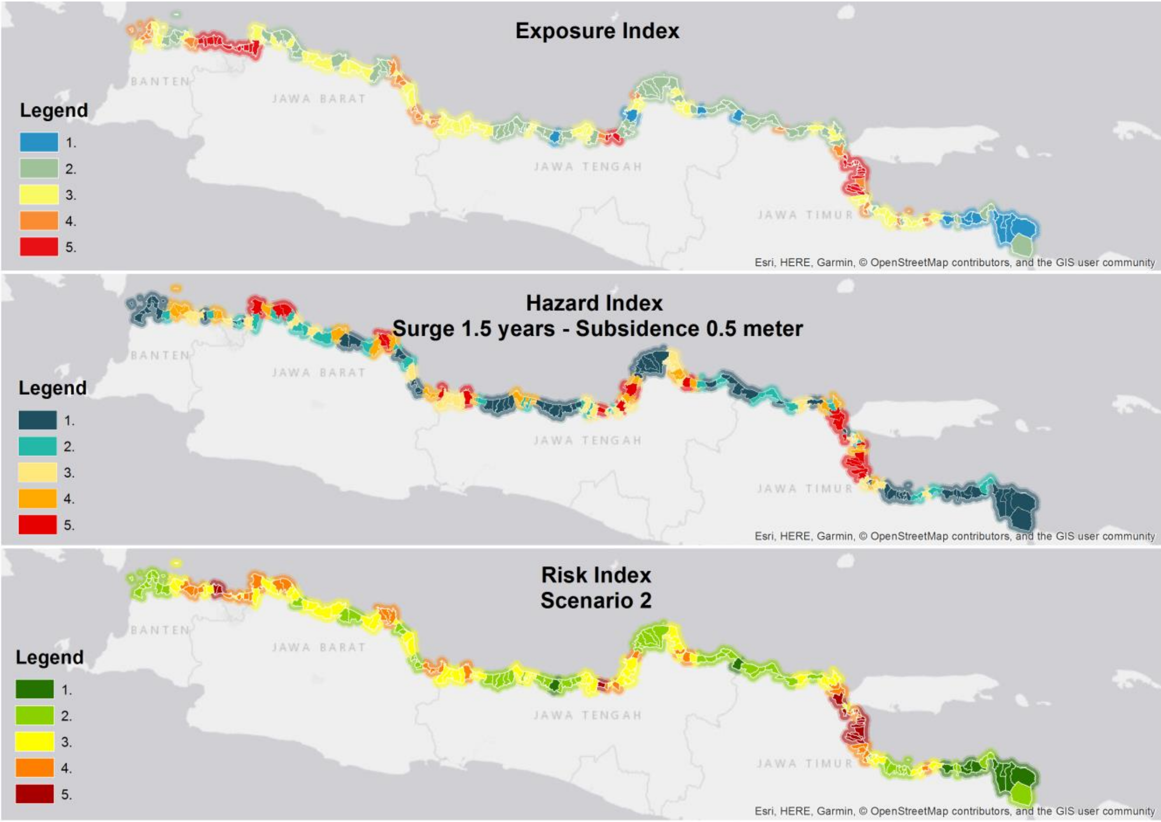

Figure B.2 . Risk of the north coast of java. The top plot shows the exposure index, the centre panel shows the hazard index for scenario 2 (SLR 0.06m, subsidence of 0.5m, surge with a return period of 1.5 year). The risk index (bottom panel) combines both the exposure and hazard index.

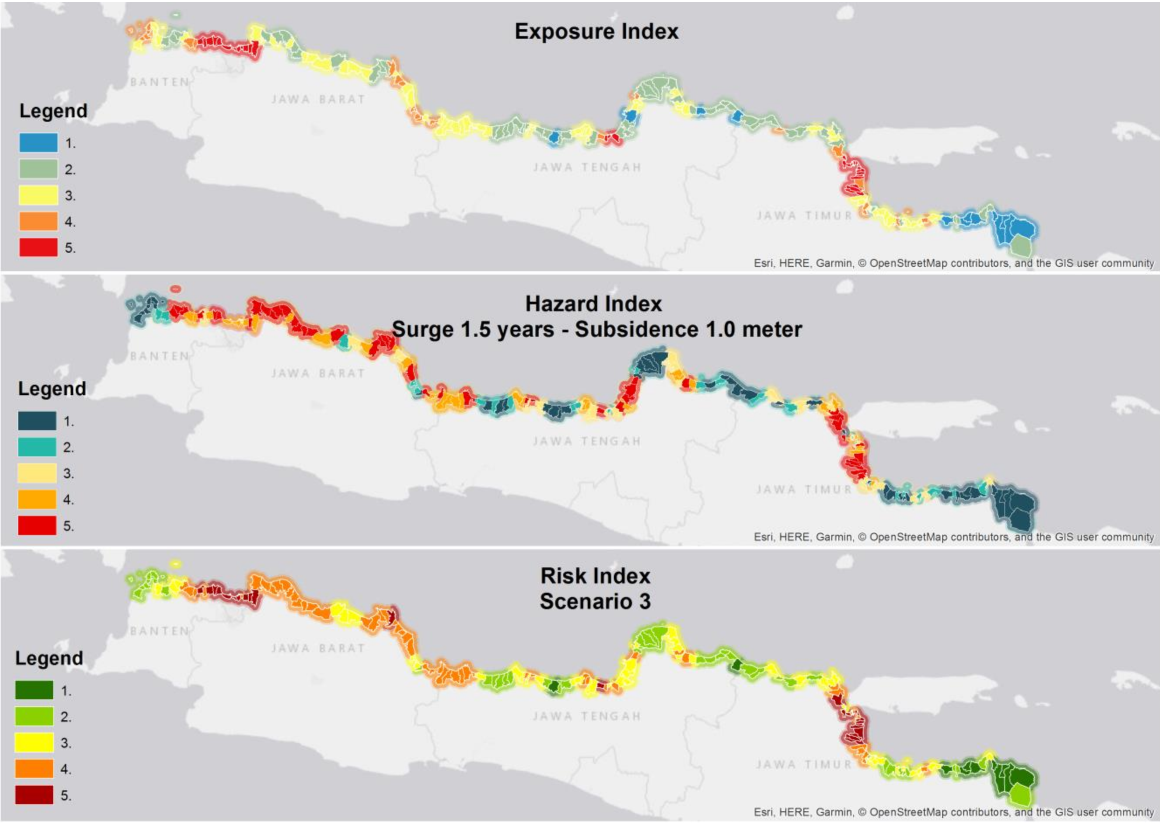

Figure B.3 Risk of the north coast of java. The top plot shows the exposure index, the centre panel shows the hazard index for scenario 3 (SLR 0.06m, subsidence of 1.0m, surge with a return period of 1.5 year). The risk index (bottom panel) combines both the exposure and hazard index.

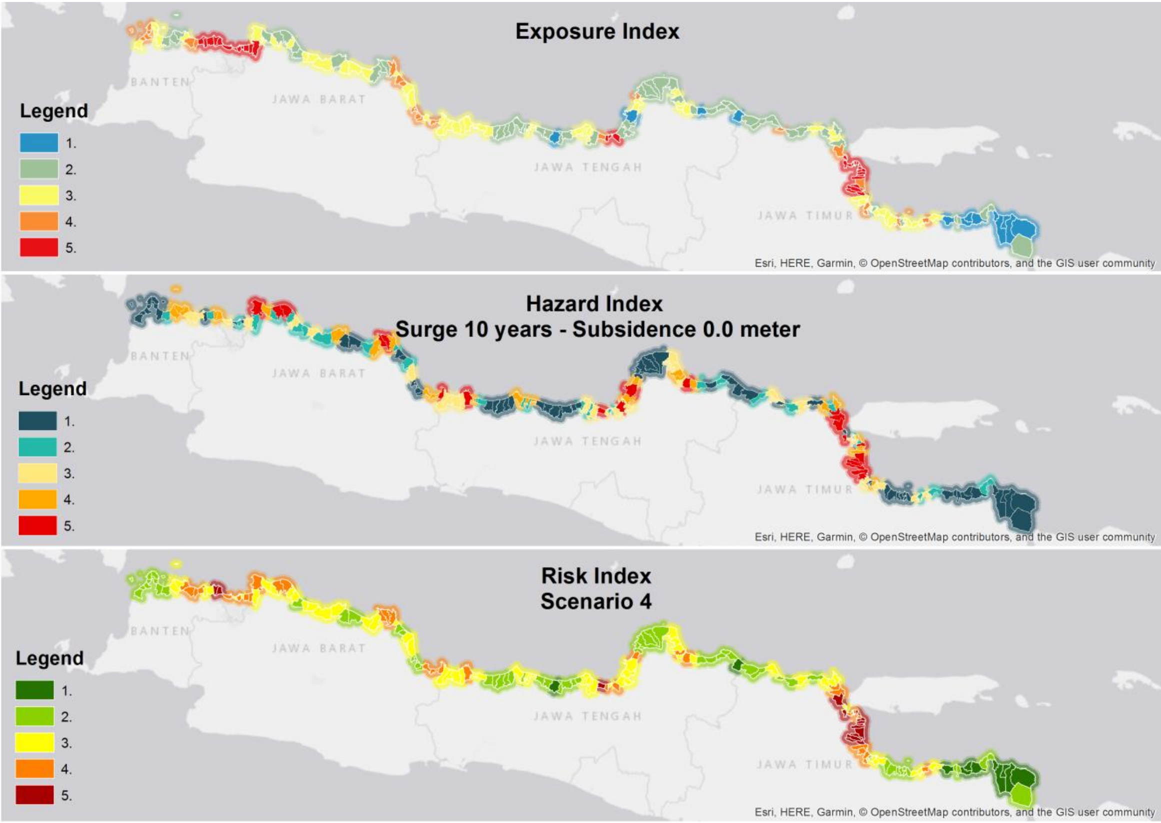

Figure B.4 Risk of the north coast of java. The top plot shows the exposure index, the centre panel shows the hazard index for scenario 4 (SLR 0.06m, subsidence of 0.0m, surge with a return period of 10 year). The risk index (bottom panel) combines both the exposure and hazard index.

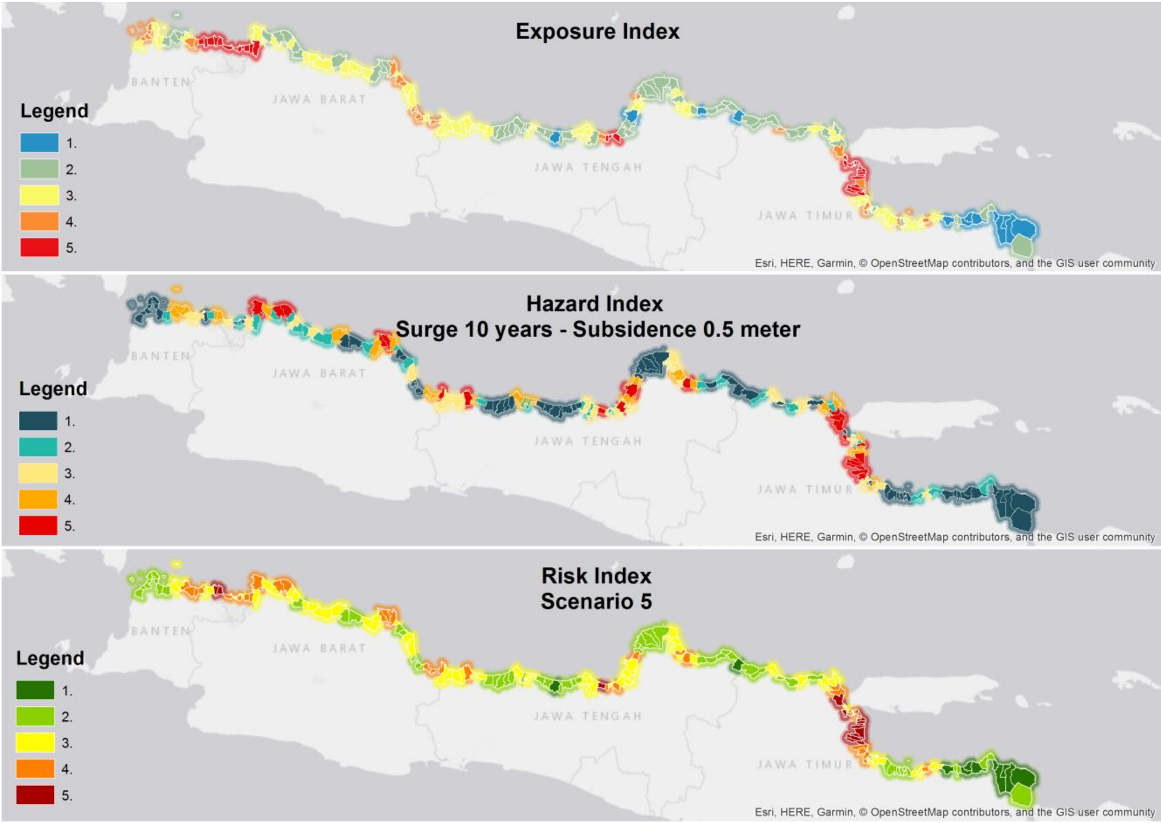

Figure B.5 Risk of the north coast of java. The top plot shows the exposure index, the centre panel shows the hazard index for scenario 5 (SLR 0.06m, subsidence of 0.5m, surge with a return period of 10 year). The risk index (bottom panel) combines both the exposure and hazard index.

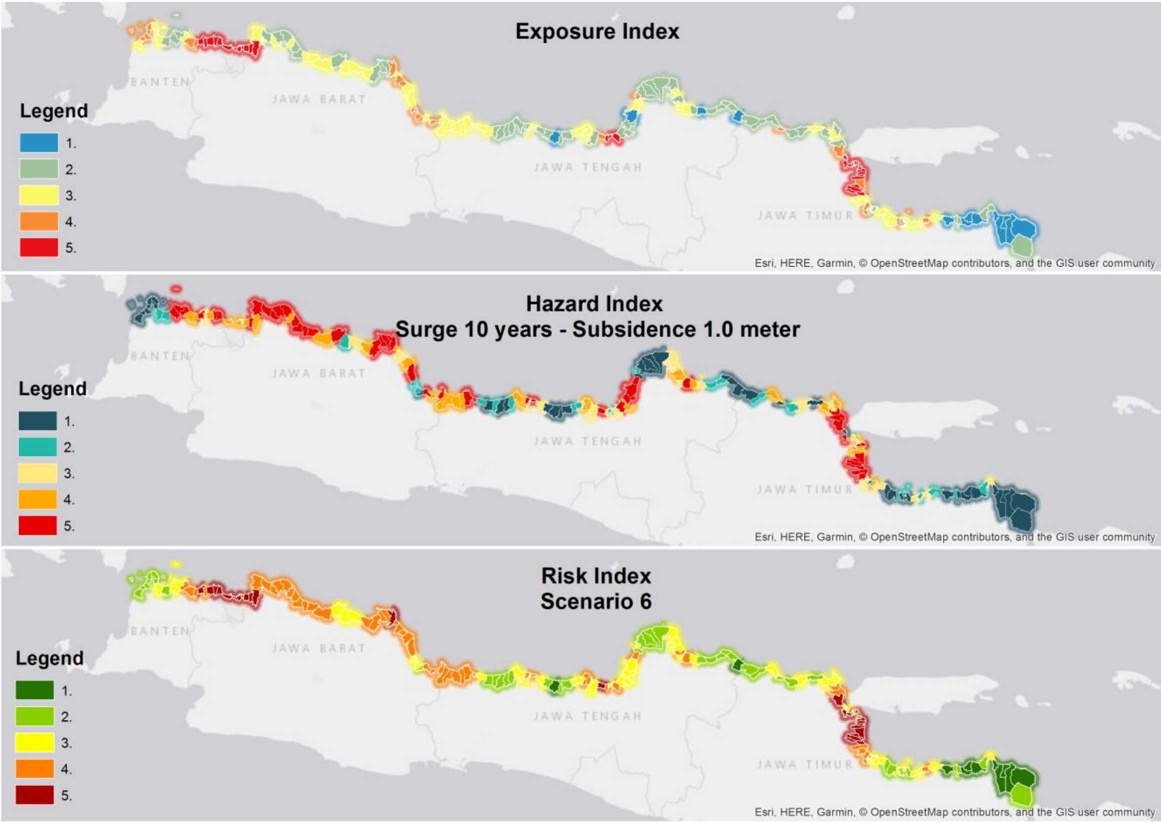

Figure B.6 Risk of the north coast of java. The top plot shows the exposure index, the centre panel shows the hazard index for scenario 6 (SLR 0.06m, subsidence of 1.0m, surge with a return period of 10 year). The risk index (bottom panel) combines both the exposure and hazard index.

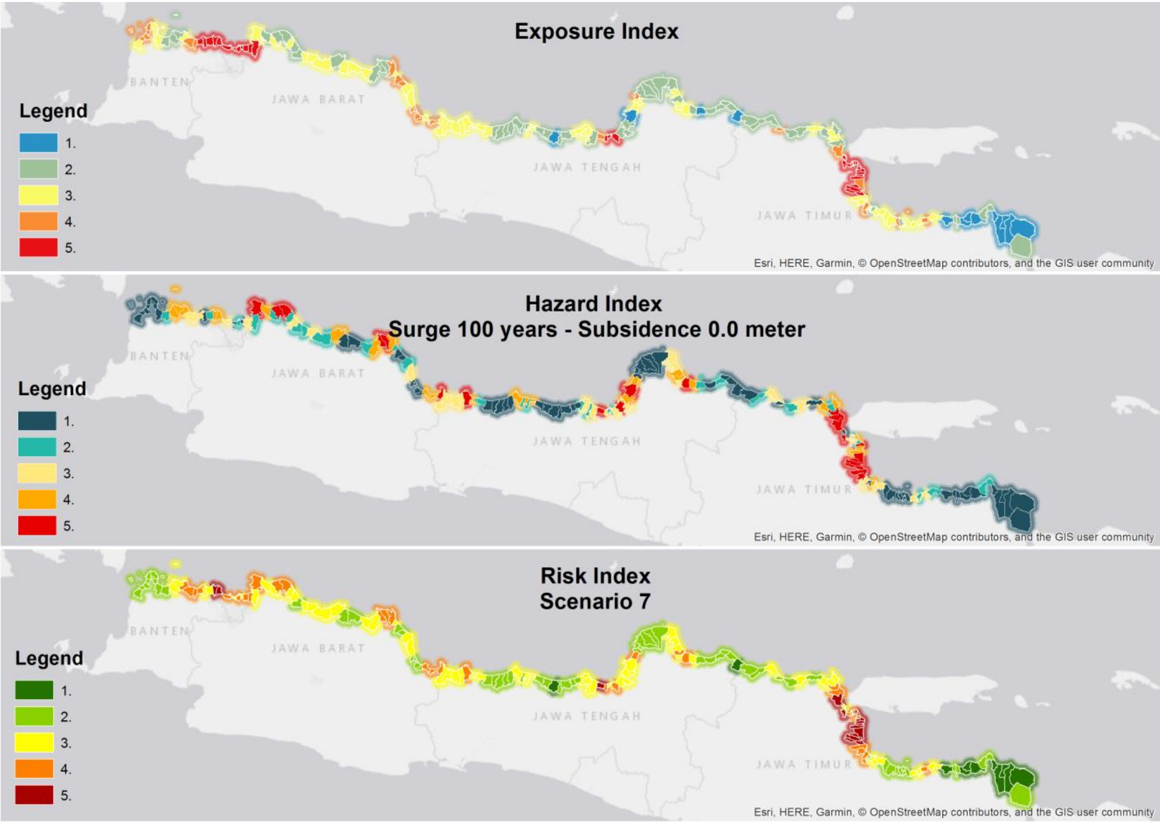

Figure B.7 . Risk of the north coast of java. The top plot shows the exposure index, the centre panel shows the hazard index for scenario 7 (SLR 0.06m, subsidence of 0.0m, surge with a return period of 100 year). The risk index (bottom panel) combines both the exposure and hazard index.

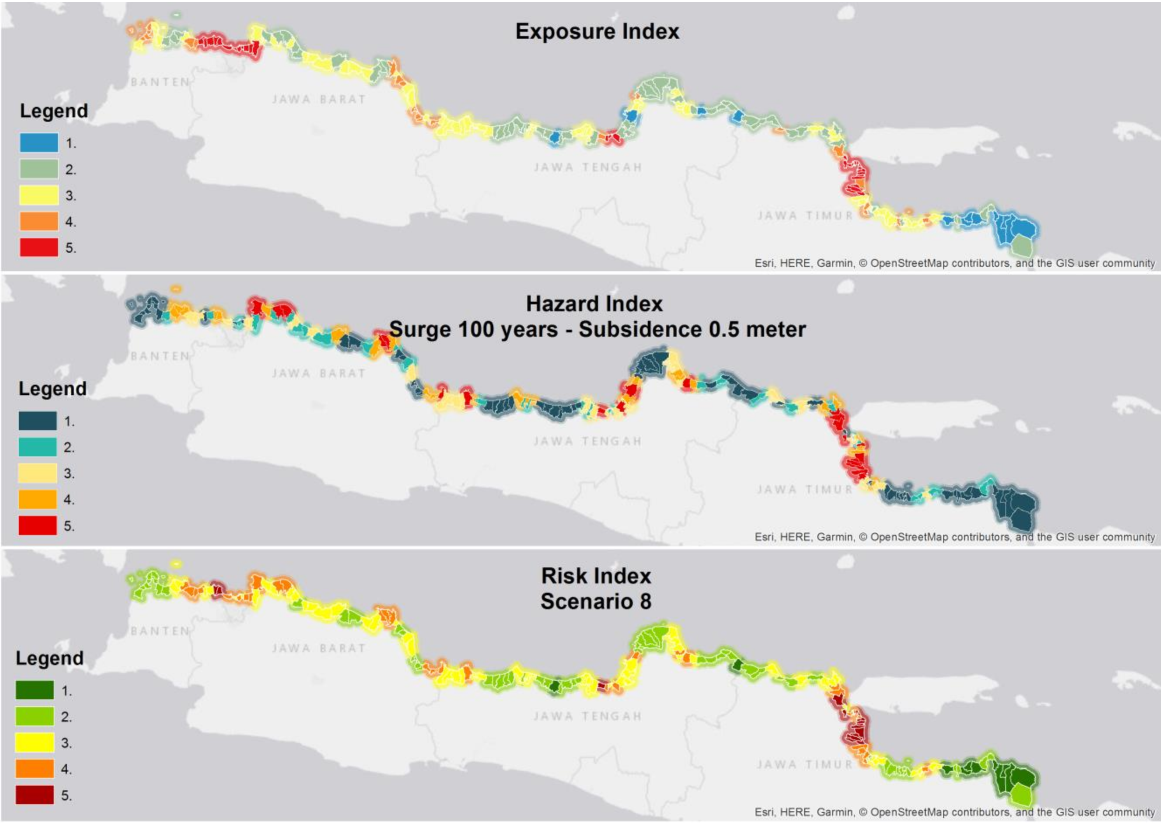

Figure B.8 . Risk of the north coast of java. The top plot shows the exposure index, the centre panel shows the hazard index for scenario 8 (SLR 0.06m, subsidence of 0.5m, surge with a return period of 100 year). The risk index (bottom panel) combines both the exposure and hazard index.

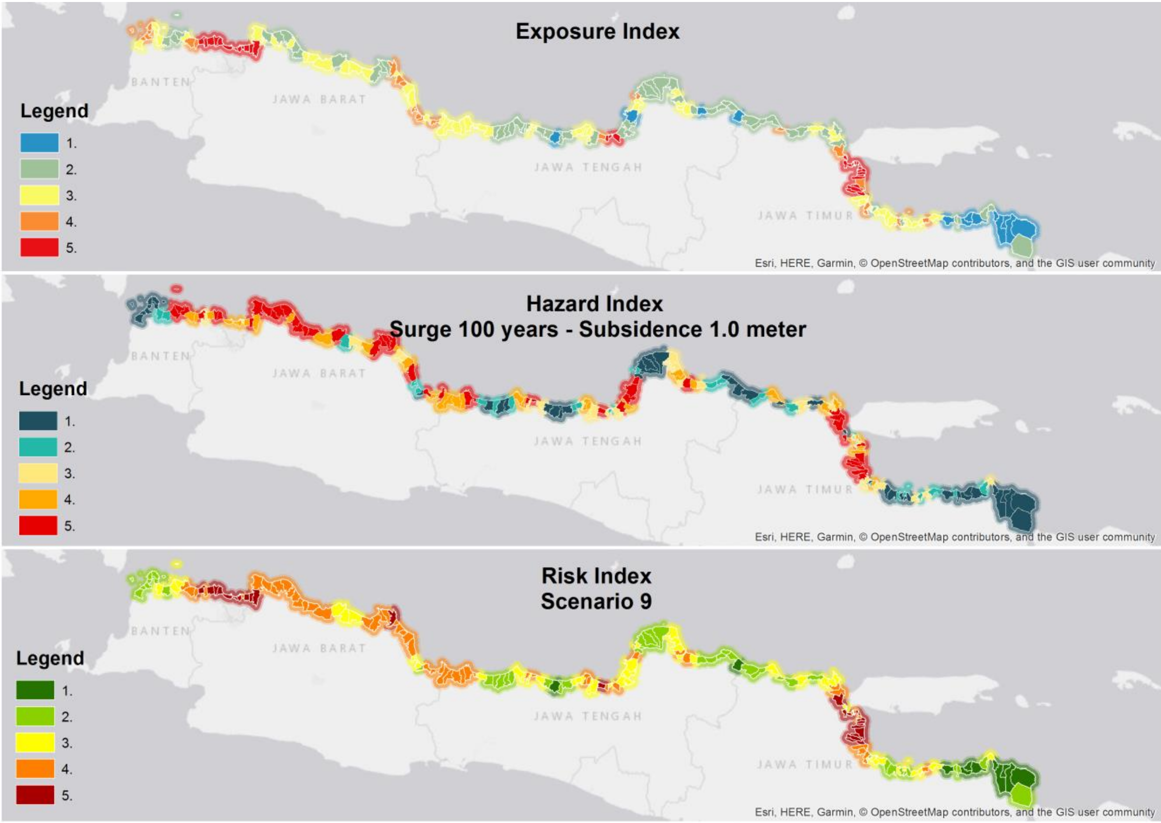

Figure B.9 . Risk of the north coast of java. The top plot shows the exposure index, the centre panel shows the hazard index for scenario 7 (SLR 0.06m, subsidence of 1.0m, surge with a return period of 100 year). The risk index (bottom panel) combines both the exposure and hazard index.

C Summary of the exposure, hazard and risk per sub-district

Province	Kabupatan	Kecamatan	Exposure Index	Hazard Index Scenario 1	Hazard Index Scenario 2	Hazard Index Scenario 3	Hazard Index Scenario 4	Hazard Index Scenario 5	Hazard Index Scenario 6	Hazard Index Scenario 7	Hazard Index Scenario 8	Hazard Index Scenario 9	Risk Index Scenario 1	Risk Index Scenario 2	Risk Index Scenario 3	Risk Index Scenario 4	Risk Index Scenario 5	Risk Index Scenario 6	Risk Index Scenario 7	Risk Index Scenario 8	Risk Index Scenario 9
JAWA BARAT	CIREBON	ASTANAJAPURA	4	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2
JAWA TENGAH	JEPARA	TAHUNAN	3	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2
JAWA BARAT	CIREBON	PANGENAN	3	4	4	5	4	4	5	4	4	5	4	4	4	4	4	4	4	4	4
JAWA TENGAH	JEPARA	JEPARA	4	1	1	2	1	1	2	1	1	2	2	2	3	2	2	3	2	2	3
JAWA BARAT	CIREBON	MUNDU	4	1	1	2	1	1	2	1	1	2	2	2	3	2	2	3	2	2	3
JAWA TENGAH	JEPARA	MLONGGO	2	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2
JAWA TENGAH	JEPARA	BANGSRI	2	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2
JAWA TENGAH	JEPARA	KEMBANG	2	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2
JAWA TENGAH	JEPARA	KELING	2	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2
DKI JAKARTA	JAKARTA UTARA	CILINCING	5	3	3	4	3	3	4	3	3	4	4	4	5	4	4	5	4	4	5
JAWA TIMUR	KAB. PROBOLINGGO	PAITON	3	2	2	2	2	2	2	2	2	2	3	3	3	3	3	3	3	3	3
JAWA TIMUR	KAB. PROBOLINGGO	KRAKSAAN	4	3	3	3	3	3	3	3	3	3	4	4	4	4	4	4	4	4	4
JAWA TENGAH	DEMAK	SAYUNG	2	5	5	5	5	5	5	5	5	5	3	3	3	3	3	3	3	3	3
JAWA BARAT	CIREBON	TENGAHTANI	4	1	1	2	1	1	2	1	1	2	2	2	3	2	2	3	2	2	3
JAWA TENGAH	DEMAK	KARANG TENGAH	2	3	3	4	3	3	4	3	3	4	3	3	3	3	3	3	3	3	3
JAWA TIMUR	KAB. PROBOLINGGO	PAJARAKAN	3	2	2	2	2	2	2	2	2	2	3	3	3	3	3	3	3	3	3
JAWA TENGAH	DEMAK	BONANG	2	4	4	5	4	4	5	4	4	5	3	3	3	3	3	3	3	3	3
JAWA BARAT	CIREBON	KAPETAKAN	3	3	3	5	3	3	5	3	3	5	3	3	4	3	3	4	3	3	4
JAWA TIMUR	KAB. PROBOLINGGO	GENDING	3	3	2	3	3	2	3	3	2	3	3	3	3	3	3	3	3	3	3
JAWA TIMUR	KAB. PROBOLINGGO	DRINGU	3	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2
JAWA TIMUR	KAB. PROBOLINGGO	TONGAS	3	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2
JAWA TIMUR	KAB. PROBOLINGGO	SUMBER ASIH	4	1	1	2	1	1	2	1	1	2	2	2	3	2	2	3	2	2	3
JAWA TENGAH	DEMAK	WEDUNG	1	5	5	5	5	5	5	5	5	5	3	3	3	3	3	3	3	3	3
DKI JAKARTA	JAKARTA UTARA	KOJA	5	1	1	3	1	1	3	1	1	3	3	3	4	3	3	4	3	3	4
DKI JAKARTA	JAKARTA UTARA	PADEMANGAN	5	1	1	4	1	1	4	1	1	4	3	3	5	3	3	5	3	3	5
JAWA TIMUR	KAB. PASURUAN	BANGIL	3	5	5	5	5	5	5	5	5	5	4	4	4	4	4	4	4	4	4
DKI JAKARTA	JAKARTA UTARA	PENJARINGAN	5	3	3	4	3	3	4	3	3	4	4	4	5	4	4	5	4	4	5
JAWA TIMUR	KAB. PASURUAN	KRATON	4	3	3	3	3	3	3	3	3	3	4	4	4	4	4	4	4	4	4
JAWA TIMUR	KAB. PASURUAN	REJOSO	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
JAWA TIMUR	KAB. PASURUAN	LEKOK	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
JAWA TIMUR	KAB. PASURUAN	NGULING	3	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2
DKI JAKARTA	JAKARTA UTARA	TANJUNG PRIOK	5	2	2	4	2	2	4	2	2	4	4	4	5	4	4	5	4	4	5
JAWA TIMUR	SIDOARJO	JABON	3	5	5	5	5	5	5	5	5	5	4	4	4	4	4	4	4	4	4
JAWA TIMUR	SIDOARJO	CANDI	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
JAWA TIMUR	SIDOARJO	SIDOARJO	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
JAWA TIMUR	SIDOARJO	BUDURAN	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
JAWA TIMUR	SIDOARJO	SEDATI	4	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
JAWA TIMUR	SIDOARJO	WARU	5	4	4	4	4	4	4	4	4	4	5	5	5	5	5	5	5	5	5
JAWA TENGAH	KENDAL	KALIWUNGU	2	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
JAWA TENGAH	KENDAL	BRANGSONG	3	2	2	3	2	2	3	2	2	3	3	3	3	3	3	3	3	3	3
JAWA TENGAH	KENDAL	ROWOSARI	3	1	1	2	1	1	2	1	1	2	2	2	3	2	2	3	2	2	3
JAWA BARAT	INDRAMAYU	KRANGKENG	3	2	2	4	2	2	4	2	2	4	3	3	4	3	3	4	3	3	4
JAWA TENGAH	KENDAL	KANGKUNG	3	1	1	2	1	1	2	1	1	2	2	2	3	2	2	3	2	2	3
JAWA BARAT	INDRAMAYU	KARANGAMPEL	4	1	1	3	1	1	3	1	1	3	2	2	4	2	2	4	2	2	4
JAWA TENGAH	KENDAL	CIPIRING	3	2	2	3	2	2	3	2	2	3	3	3	3	3	3	3	3	3	3
JAWA TENGAH	KENDAL	PATEBON	3	3	3	4	3	3	4	3	3	4	3	3	4	3	3	4	3	3	4
JAWA BARAT	INDRAMAYU	JUNTINYUAT	4	1	1	3	1	1	3	1	1	3	2	2	4	2	2	4	2	2	4
JAWA TENGAH	KENDAL	KOTA KENDAL	3	3	3	4	3	3	4	3	3	4	3	3	4	3	3	4	3	3	4
JAWA BARAT	INDRAMAYU	BALONGAN	3	2	2	4	2	2	4	2	2	4	3	3	4	3	3	4	3	3	4
JAWA BARAT	INDRAMAYU	INDRAMAYU	4	4	4	5	4	4	5	4	4	5	4	4	5	4	4	5	4	4	5
JAWA BARAT	INDRAMAYU	SINDANG	2	5	5	5	5	5	5	5	5	5	4	4	4	4	4	4	4	4	4
JAWA TIMUR	KOTA PROBOLINGGO	KADEMANGAN	2	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2

Province	Kabupatan	Kecamatan	Exposure Index	Hazard Index Scenario 1	Hazard Index Scenario 2	Hazard Index Scenario 3	Hazard Index Scenario 4	Hazard Index Scenario 5	Hazard Index Scenario 6	Hazard Index Scenario 7	Hazard Index Scenario 8	Hazard Index Scenario 9	Risk Index Scenario 1	Risk Index Scenario 2	Risk Index Scenario 3	Risk Index Scenario 4	Risk Index Scenario 5	Risk Index Scenario 6	Risk Index Scenario 7	Risk Index Scenario 8	Risk Index Scenario 9
JAWA BARAT	INDRAMAYU	CANTIGI	2	5	5	5	5	5	5	5	5	5	4	4	4	4	4	4	4	4	4
JAWA TIMUR	KOTA PROBOLINGGO	WONOASIH	3	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2
JAWA TENGAH	BATANG	GRINGSING	2	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2
JAWA TIMUR	KOTA PROBOLINGGO	MAYANGAN	3	1	1	2	1	1	2	1	1	2	2	2	3	2	2	3	2	2	3
JAWA TENGAH	BATANG	LIMPUNG	2	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2
JAWA TIMUR	KOTA PASURUAN	GADINGREJO	3	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2
JAWA BARAT	INDRAMAYU	LOSARANG	2	4	4	5	4	4	5	4	4	5	3	3	4	3	3	4	3	3	4
JAWA TENGAH	BATANG	SUBAH	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
JAWA TIMUR	KOTA PASURUAN	PURWOREJO	3	1	1	2	1	1	2	1	1	2	2	2	3	2	2	3	2	2	3
JAWA TENGAH	BATANG	TULIS	2	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2
JAWA TIMUR	KOTA PASURUAN	BUGULKIDUL	2	4	4	4	4	4	4	4	4	4	3	3	3	3	3	3	3	3	3
JAWA BARAT	INDRAMAYU	KANDANGHAUR	3	2	2	4	2	2	4	2	2	4	3	3	4	3	3	4	3	3	4
JAWA TENGAH	BATANG	BATANG	2	1	1	3	1	1	3	1	1	3	2	2	3	2	2	3	2	2	3
JAWA BARAT	INDRAMAYU	SUKRA	3	1	1	3	1	1	3	1	1	3	2	2	3	2	2	3	2	2	3
JAWA TIMUR	SURABAYA	GUNUNG ANYAR	5	4	4	4	4	4	4	4	4	4	5	5	5	5	5	5	5	5	5
JAWA TIMUR	SURABAYA	RUNGKUT	5	4	4	4	4	4	4	4	4	4	5	5	5	5	5	5	5	5	5
JAWA TENGAH	PEKALONGAN	SIWALAN	2	2	2	4	2	2	4	2	2	4	2	2	3	2	2	3	2	2	3
JAWA TIMUR	SURABAYA	SUKOLILO	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
JAWA TIMUR	SURABAYA	MULYOREJO	5	2	2	3	2	2	3	2	2	3	4	4	4	4	4	4	4	4	4
JAWA TENGAH	PEKALONGAN	TIRTO	3	2	2	3	2	2	3	2	2	3	3	3	3	3	3	3	3	3	3
JAWA TENGAH	PEKALONGAN	WONOKERTO	2	4	4	5	4	4	5	4	4	5	3	3	4	3	3	4	3	3	4
JAWA BARAT	SUBANG	PUSAKANAGARA	3	1	1	2	1	1	2	1	1	2	2	2	3	2	2	3	2	2	3
JAWA BARAT	SUBANG	LEGONKULON	2	4	4	5	4	4	5	4	4	5	3	3	3	3	3	3	3	3	3
JAWA BARAT	SUBANG	BLANAKAN	3	2	2	4	2	2	4	2	2	4	3	3	4	3	3	4	3	3	4
JAWA TIMUR	SURABAYA	KENJERAN	5	4	4	4	4	4	4	4	4	4	5	5	5	5	5	5	5	5	5
JAWA TIMUR	SURABAYA	BULAK	5	4	4	4	4	4	4	4	4	4	5	5	5	5	5	5	5	5	5
JAWA TENGAH	PEMALANG	PEMALANG	2	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2
JAWA TIMUR	SURABAYA	SEMAMPIR	5	3	3	3	3	3	3	3	3	3	4	4	4	4	4	4	4	4	4
JAWA TENGAH	PEMALANG	TAMAN	2	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2
JAWA TIMUR	SURABAYA	PABEAN CANTIAN	5	2	2	2	2	2	2	2	2	2	4	4	4	4	4	4	4	4	4
JAWA TENGAH	PEMALANG	PETARUKAN	2	1	1	2	1	1	2	1	1	2	2	2	2	2	2	2	2	2	2
JAWA TIMUR	SURABAYA	KREMBANGAN	5	3	3	3	3	3	3	3	3	3	4	4	4	4	4	4	4	4	4
JAWA TIMUR	SURABAYA	ASEMROWO	5	3	3	4	3	3	4	3	3	4	4	4	5	4	4	5	4	4	5
JAWA TENGAH	PEMALANG	ULUJAMI	2	4	4	4	4	4	4	4	4	4	3	3	3	3	3	3	3	3	3
JAWA TIMUR	SURABAYA	BENOWO	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
BANTEN	SERANG	ANYAR	3	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2
BANTEN	SERANG	BOJONEGARA	3	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2
JAWA TENGAH	TEGAL	KRAMAT	3	2	2	2	2	2	2	2	2	2	3	3	3	3	3	3	3	3	3
JAWA TENGAH	TEGAL	SURADADI	3	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2
JAWA TENGAH	TEGAL	WARUREJA	2	1	1	2	1	1	2	1	1	2	2	2	2	2	2	2	2	2	2
JAWA BARAT	KARAWANG	CILAMAYA WETAN	3	3	3	5	3	3	5	3	3	5	3	3	4	3	3	4	3	3	4
JAWA BARAT	KARAWANG	CILAMAYA KULON	3	2	2	5	2	2	5	2	2	5	3	3	4	3	3	4	3	3	4
JAWA TENGAH	BREBES	LOSARI	3	3	3	4	3	3	4	3	3	4	3	3	4	3	3	4	3	3	4
JAWA BARAT	KARAWANG	TEMPURAN	2	2	2	5	2	2	5	2	2	5	2	2	4	2	2	4	2	2	4
JAWA TENGAH	BREBES	TANJUNG	3	3	3	4	3	3	4	3	3	4	3	3	4	3	3	4	3	3	4
JAWA TENGAH	BREBES	BULAKAMBA	3	3	3	4	3	3	4	3	3	4	3	3	4	3	3	4	3	3	4
JAWA TENGAH	BREBES	WANASARI	3	3	3	4	3	3	4	3	3	4	3	3	4	3	3	4	3	3	4
JAWA BARAT	KARAWANG	PEDES	3	2	2	4	2	2	4	2	2	4	3	3	4	3	3	4	3	3	4
JAWA BARAT	KARAWANG	CILEBAR	2	3	3	5	3	3	5	3	3	5	3	3	4	3	3	4	3	3	4
JAWA BARAT	KARAWANG	CIBUAYA	2	5	5	5	5	5	5	5	5	5	4	4	4	4	4	4	4	4	4
JAWA TENGAH	BREBES	BREBES	3	5	5	5	5	5	5	5	5	5	4	4	4	4	4	4	4	4	4
JAWA BARAT	KARAWANG	TIRTAJAYA	2	5	5	5	5	5	5	5	5	5	4	4	4	4	4	4	4	4	4

Province	Kabupatan	Kecamatan	Exposure Index	Hazard Index Scenario 1	Hazard Index Scenario 2	Hazard Index Scenario 3	Hazard Index Scenario 4	Hazard Index Scenario 5	Hazard Index Scenario 6	Hazard Index Scenario 7	Hazard Index Scenario 8	Hazard Index Scenario 9	Risk Index Scenario 1	Risk Index Scenario 2	Risk Index Scenario 3	Risk Index Scenario 4	Risk Index Scenario 5	Risk Index Scenario 6	Risk Index Scenario 7	Risk Index Scenario 8	Risk Index Scenario 9
JAWA BARAT	KARAWANG	BATUJAYA	3	2	2	5	2	2	5	2	2	5	3	3	4	3	3	4	3	3	4
JAWA BARAT	KARAWANG	PAKISJAYA	2	4	4	5	4	4	5	4	4	5	3	3	4	3	3	4	3	3	4
BANTEN	CILEGON	CITANGKIL	4	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2
BANTEN	CILEGON	CIWANDAN	4	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2
JAWA BARAT	BEKASI	BABELAN	5	2	2	4	2	2	4	2	2	4	3	3	5	3	3	5	3	3	5
JAWA BARAT	BEKASI	TARUMAJAYA	5	3	3	5	3	3	5	3	3	5	4	4	5	4	4	5	4	4	5
BANTEN	CILEGON	GEROGOL	4	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2
JAWA TENGAH	SEMARANG	GENUK	5	3	3	3	3	3	3	3	3	3	4	4	4	4	4	4	4	4	4
JAWA TENGAH	SEMARANG	SEMARANG UTARA	5	2	2	2	2	2	2	2	2	2	3	3	3	3	3	3	3	3	3
JAWA TENGAH	SEMARANG	SEMARANG BARAT	5	3	3	3	3	3	3	3	3	3	4	4	4	4	4	4	4	4	4
JAWA BARAT	BEKASI	MUARA GEMBONG	3	5	5	5	5	5	5	5	5	5	4	4	4	4	4	4	4	4	4
JAWA TENGAH	SEMARANG	TUGU	4	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
JAWA TENGAH	PEKALONGAN	PEKALONGAN UTARA	3	4	4	5	4	4	5	4	4	5	3	3	4	3	3	4	3	3	4
BANTEN	SERANG	KASEMEN	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
BANTEN	TANGERANG	KEMIRI	4	3	3	4	3	3	4	3	3	4	4	4	4	4	4	4	4	4	4
JAWA TENGAH	TEGAL	TEGAL TIMUR	3	2	2	2	2	2	2	2	2	2	3	3	3	3	3	3	3	3	3
JAWA TENGAH	TEGAL	TEGAL BARAT	3	4	4	5	4	4	5	4	4	5	3	3	4	3	3	4	3	3	4
BANTEN	TANGERANG	KOSAMBI	5	4	4	5	4	4	5	4	4	5	5	5	5	5	5	5	5	5	5
BANTEN	SERANG	KRAMATWATU	3	1	1	2	1	1	2	1	1	2	2	2	3	2	2	3	2	2	3
BANTEN	TANGERANG	KRONJO	4	3	3	4	3	3	4	3	3	4	4	4	4	4	4	4	4	4	4
JAWA TIMUR	TUBAN	PALANG	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
BANTEN	TANGERANG	MAUK	5	3	3	5	3	3	5	3	3	5	4	4	5	4	4	5	4	4	5
JAWA TIMUR	TUBAN	TUBAN	4	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2
JAWA TIMUR	TUBAN	JENU	2	2	2	3	3	3	4	3	3	4	2	2	3	3	3	3	3	3	3
JAWA TIMUR	TUBAN	TAMBAKBOYO	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
JAWA TENGAH	REMBANG	SARANG	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
JAWA TIMUR	TUBAN	BANCAR	2	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2
BANTEN	TANGERANG	PAKUHAJI	5	2	2	4	2	2	4	2	2	4	3	3	5	3	3	5	3	3	5
JAWA TENGAH	REMBANG	KALIORI	1	2	2	2	2	2	3	2	2	3	2	2	2	2	2	2	2	2	2
JAWA TENGAH	REMBANG	REMBANG	2	1	1	1	1	1	2	1	1	2	2	2	2	2	2	2	2	2	2
JAWA TIMUR	BANYUWANGI	WONGSOREJO	2	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2
JAWA TENGAH	REMBANG	KRAGAN	2	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2
JAWA TENGAH	REMBANG	SLUKE	2	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2
JAWA TENGAH	REMBANG	LASEM	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
JAWA BARAT	KOTA CIREBON	LEMAHWUNGKUK	4	1	1	2	1	1	2	1	1	2	2	2	3	2	2	3	2	2	3
JAWA BARAT	KOTA CIREBON	KEJAKSAN	4	1	1	2	1	1	2	1	1	2	2	2	3	2	2	3	2	2	3
JAWA TENGAH	PATI	BATANGAN	2	4	4	4	4	4	4	4	4	4	3	3	3	3	3	3	3	3	3
JAWA TENGAH	PATI	JUWANA	3	5	5	5	5	5	5	5	5	5	4	4	4	4	4	4	4	4	4
BANTEN	SERANG	PONTANG	2	4	4	5	4	4	5	4	4	5	3	3	3	3	3	3	3	3	3
BANTEN	SERANG	PULO AMPEL	3	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2
BANTEN	CILEGON	PULOMERAK	4	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2
JAWA TENGAH	PATI	WEDARIJAKSA	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
JAWA TENGAH	PATI	TRANGKIL	3	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
JAWA TENGAH	PATI	MARGOYOSO	2	4	4	4	4	4	4	4	4	4	3	3	3	3	3	3	3	3	3
JAWA TIMUR	LAMONGAN	PACIRAN	3	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2
JAWA TIMUR	LAMONGAN	BRONDONG	2	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
JAWA TIMUR	SITUBONDO	BANYUGLUGUR	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
JAWA TENGAH	PATI	TAYU	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
JAWA TIMUR	SITUBONDO	BESUKI	2	1	1	2	1	1	2	1	1	2	2	2	2	2	2	2	2	2	2
BANTEN	TANGERANG	SUKADIRI	5	1	1	3	1	1	3	1	1	3	3	3	4	3	3	4	3	3	4
JAWA TENGAH	PATI	DUKUHSETI	2	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
JAWA TIMUR	SITUBONDO	SUBOH	2	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2

Province	Kabupatan	Kecamatan	Exposure Index	Hazard Index Scenario 1	Hazard Index Scenario 2	Hazard Index Scenario 3	Hazard Index Scenario 4	Hazard Index Scenario 5	Hazard Index Scenario 6	Hazard Index Scenario 7	Hazard Index Scenario 8	Hazard Index Scenario 9	Risk Index Scenario 1	Risk Index Scenario 2	Risk Index Scenario 3	Risk Index Scenario 4	Risk Index Scenario 5	Risk Index Scenario 6	Risk Index Scenario 7	Risk Index Scenario 8	Risk Index Scenario 9
JAWA TIMUR	SITUBONDO	MLANDINGAN	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
JAWA TIMUR	SITUBONDO	BUNGATAN	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
BANTEN	SERANG	TANARA	3	4	4	5	4	4	5	4	4	5	4	4	4	4	4	4	4	4	4
JAWA TIMUR	SITUBONDO	KENDIT	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
JAWA TIMUR	SITUBONDO	PANARUKAN	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
BANTEN	TANGERANG	TELUKNAGA	5	4	4	5	4	4	5	4	4	5	5	5	5	5	5	5	5	5	5
JAWA TIMUR	SITUBONDO	MANGARAN	2	2	2	3	2	2	3	2	2	3	2	2	3	2	2	3	2	2	3
BANTEN	SERANG	TIRTAYASA	2	4	4	5	4	4	5	4	4	5	3	3	3	3	3	3	3	3	3
JAWA BARAT	CIREBON	LOSARI	3	5	5	5	5	5	5	5	5	5	4	4	4	4	4	4	4	4	4
JAWA TIMUR	GRESIK	GRESIK	5	1	1	1	1	1	1	1	1	1	3	3	3	3	3	3	3	3	3
JAWA TIMUR	SITUBONDO	KAPONGAN	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
JAWA TIMUR	GRESIK	MANYAR	4	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
JAWA TIMUR	SITUBONDO	ARJASA	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
JAWA TENGAH	JEPARA	KEDUNG	3	4	4	5	4	4	5	4	4	5	4	4	4	4	4	4	4	4	4
JAWA TIMUR	GRESIK	BUNGAH	2	5	5	5	5	5	5	5	5	5	4	4	4	4	4	4	4	4	4
JAWA TIMUR	SITUBONDO	JANGKAR	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
JAWA BARAT	CIREBON	GEBANG	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
JAWA TIMUR	GRESIK	SIDAYU	3	5	5	5	5	5	5	5	5	5	4	4	4	4	4	4	4	4	4
JAWA TIMUR	SITUBONDO	ASEMBAGUS	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
JAWA TIMUR	SITUBONDO	BANYUPUTIH	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
JAWA TIMUR	GRESIK	PANCENG	2	4	4	4	4	4	4	4	4	4	3	3	3	3	3	3	3	3	3
JAWA TIMUR	GRESIK	UJUNGPANGKAH	3	2	2	3	2	2	3	2	2	3	3	3	3	3	3	3	3	3	3